FERROCEMENT: Applications in Developing Countries

NATIONAL ACADEMY OF SCIENCES
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Ferrocement: Applications in Developing Countries

A Report of an Ad Hoc Panel of the
Advisory Committee on Technological Innovation
Board on Science and Technology for International Development
Office of the Foreign Secretary

Con Resumen En Español
Avec Résumé En Français

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OFFICE OF THE FOREIGN SECRETARY

February, 1973

Dr. Joel Bernstein
Assistant Administrator
Bureau for Technical Assistance
Agency for International Development
Department of State
Washington, D.C. 20523

Dear Dr. Bernstein:

Ferrocement, a thin-shell concrete reinforced with wire mesh, is a high-quality construction material whose ingredients are widely available in developing countries. It can be used to build a wide range of structures, and can be worked mainly by unskilled, though supervised, labor. Throughout the world, highly satisfactory fishing boats, pleasure craft, storage tanks, housing components, and assorted agricultural and commercial facilities have been construced of ferrocement, and its use is increasing rapidly.

With a view toward its future impact, the Ad Hoc Panel on the Utilization of Ferrocement in Developing Countries was convened by the Board on Science and Technology for International Development as part of its continuing study of technological innovations relevant to the problems of developing countries. The panel included some persons experienced in successful applications of ferrocement to land and water uses and others familiar with construction needs in developing countries. The panel concentrated on three specific tasks:

- Evaluating the current state of the art of ferrocement as an engineering material in order to identify its known properties and characteristics.
- Evaluating the principal areas of application on both land and water.
- Developing specific recommendations for promoting the use of ferrocement in a logical, effective manner.

The report considers the potential for further use of already discovered applications, such as boats and silos, and identifies promising new applications, such as roofs and food-processing equipment. The panel concludes that

the potential of ferrocement in developing countries and its likely effect on their economies are much greater than previously thought.

Deliberately scant in technical language and brief in documentation, the report is detailed enough to provide a clear understanding of what ferrocement is and what it can do. In particular, this report seeks to convey a sense of ferrocement's wide-ranging potential to readers in developing countries—government officials, technical assistance representatives, and technical experts—who are becoming more curious about this increasingly discussed technology.

Sincerely yours,

Harrison Brown
Foreign Secretary

In the final stages of the preparation of this report we were saddened to learn of the death of W. Morley Sutherland. During the past 15 years he had played a preeminent role in the development of ferrocement for boatbuilding. He brought intense personal dedication and wide practical experience to the deliberations of the panel.

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Preface

The National Academy of Sciences, through its Board on Science and Technology for International Development (BOSTID), has been concerned for many years with the application of science and technology to international economic development. The activities of the board have been largely supported by the U.S. Agency for International Development (AID).

Recently, at the request of AID, the Board established an Advisory Committee on Technological Innovation (ACTI) to oversee a continuing, systematic search for, and assessment of, developments in fields of science and technology that may bear particular relevance to the solution of specific problems of developing countries.

An early inquiry referred to ACTI concerned the replacement of the fishing fleet destroyed in the November, 1970, cyclone in what was then East Pakistan. AID wished to obtain information on innovations in boat-building techniques that would accelerate the reconstruction of this desperately needed resource. Preliminary investigations showed that ferrocement held substantial promise for boatbuilding and, indeed, for many other applications. To explore the broad potential of this material for both water and land uses, the board convened the Ad Hoc Panel on the Utilization of Ferrocement in Developing Countries.

This report is the result of the panel's deliberations during three 1-day meetings in Washington, D.C., and a 4-day session at Airlie House, Virginia, in the course of 1972.

During deliberations the panel often felt need of an analysis of the materials science and basic engineering of ferrocement. No such analysis exists, and the widespread fragmentation and scatter of data through the literature make conclusions and comparisons difficult. The panel recommends that a

document on the materials science of ferrocement be prepared by a panel chosen for this purpose.

The panel's efforts have been greatly assisted by Mignon Cabanilla, Administrative Secretary to the Advisory Committee on Technological Innovation, and by Jane Lecht, the BOSTID editor.

Contents

CHAPTER *I*

Summary and Recommendations

Ferrocement is a highly versatile form of reinforced concrete made of wire mesh, sand, water, and cement, which possesses unique qualities of strength and serviceability. It can be constructed with a minimum of skilled labor and utilizes readily available materials. Proven suitable for boatbuilding, it has many other tested or potential applications in agriculture, industry, and housing.

Ferrocement is particularly suited to developing countries for the following reasons:

- Its basic raw materials are available in most countries.
- It can be fabricated into almost any shape to meet the needs of the user; traditional designs can be reproduced and often improved. Properly fabricated, it is more durable than most woods and much cheaper than imported steel, and it can be used as a substitute for these materials in many applications.
- The skills for ferrocement construction are quickly acquired, and include many skills traditional in developing countries. Ferrocement construction does not need heavy plant or machinery; it is labor-intensive. Except for sophisticated and highly stressed designs, as those for deep-water vessels, a trained supervisor can achieve the requisite amount of quality control using fairly unskilled labor for the fabrication.

The following specific recommendations are based on documentation of

the current state of the art and the ad hoc panel's own evaluation of selected water and land applications of ferrocement, detailed later in this report.

RECOMMENDATION 1: Exploratory Research into the Full Range of Ferrocement Applications

The panel recommends that ferrocement be subjected to a wide-ranging program of research and development to explore all its potential uses. Such R & D is likely to produce many valuable applications for the developing world.

Some applications require laboratory analysis (e.g., interactions between stored food and mortar surfaces); some, structural testing; some, demonstration and pilot trials. Other are so speculative that only studies on paper are warranted at present. Research institutions, engineering laboratories, corporations with R & D capability, technical schools, universities, or innovative individuals can engage in this work. Exploration of these ferrocement appli-

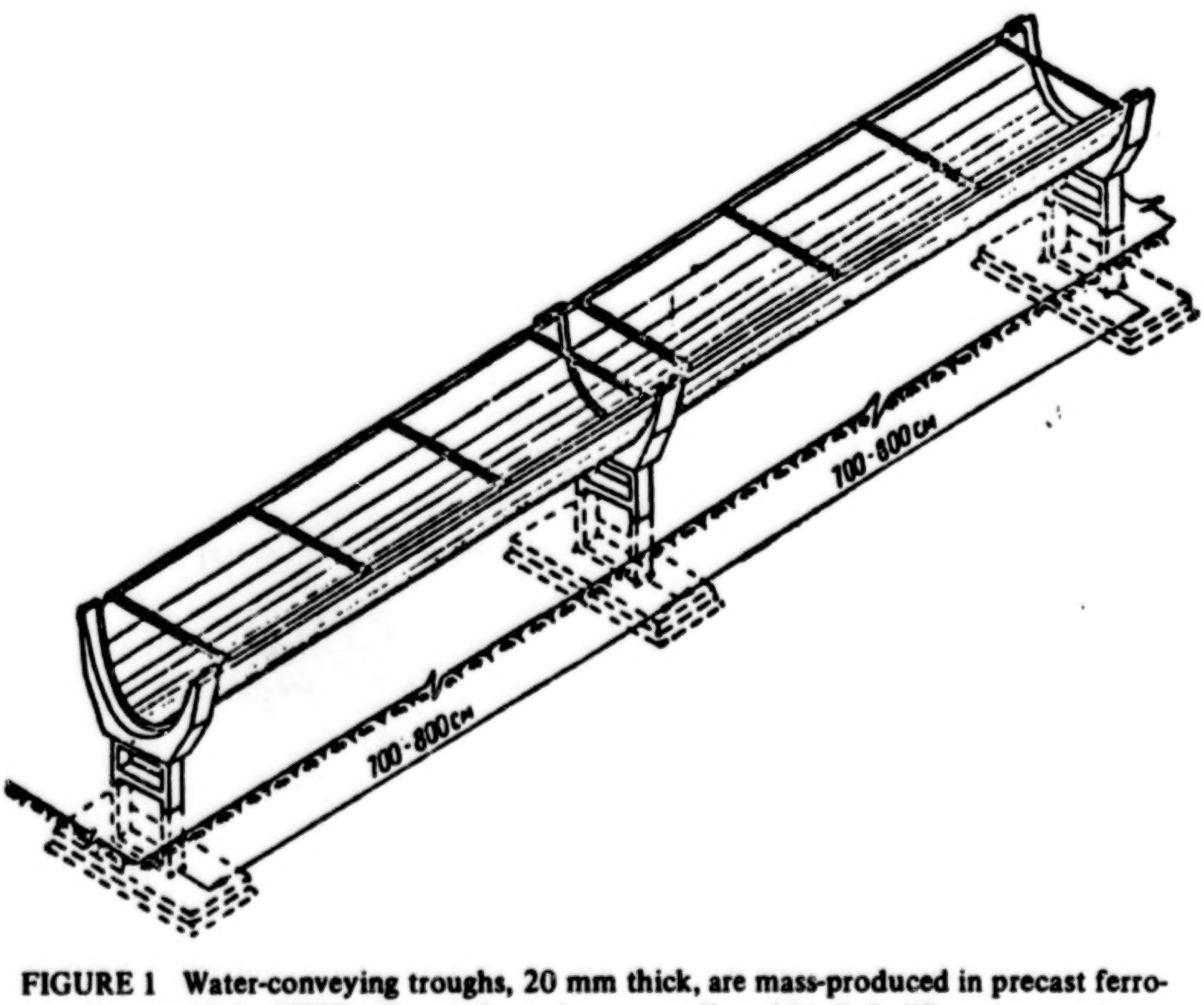


FIGURE 1 Water-conveying troughs, 20 mm thick, are mass-produced in precast ferrocement units in the USSR. (Drawn from diagram in Kowalski, T.G. "Ferrocement in Hong Kong." *Far East Builder*. July 1971. p. 29.)

cations is exceptionally well suited for work on location in the developing world, but a role for research in industrialized nations exists. Although this report stresses less sophisticated applications, ferrocement is adaptable to sophisticated technology, too. Factory-fabricated precision components made from ferrocement may ultimately be the main use of the material. One particularly promising area for more sophisticated R & D is in replacing ferrocement with chopped-wire concrete in which randomly placed short lengths of wire, mixed in with the mortar, take the place of wire mesh.

Following is a list of individual applications the panel felt were particularly worthy of detailed investigation. Some of these applications are specifically discussed in Recommendations 2-6. They are included here to convey a sense of the range of uses for ferrocement. (See also Figures 1-5.)

POTENTIAL APPLICATIONS OF FERROCEMENT

- Fishing and Cargo Boats
- Tugs and Barges
- Bridges
- Docks and Marinas
- Permanent food-storage dumps
- Seed (vegetables, etc.) storage
- Starch, flour, sugar storage
- Silage storage
- Edible oil storage (olive, peanut, cottonseed, palm, etc.)
- Grain storage (rice, wheat, corn, sorghum, millet, etc.)
- Manioc-soaking vats
- Fermentation tanks for cocoa, coffee, etc.
- Retting tanks for sisal, jute, hemp, etc.
- Gas tanks (for liquid and natural gas)
- Cooling towers
- Sewage troughs, lagoons, septic tanks, and other treatment facilities
- Guttering
- Leather-processing facilities
- Dyeing vats
- Grain dryers
- Copra dryers
- Greenhouse, packinghouse, and drying tables
- Pads for drying tea, coffee, cocoa, coconuts, other oilseeds, peppers, spices, etc.
- Cattle feeders and water troughs
- Cattle dips
- Water storage (drinking or irrigation)
- Pipes and irrigation conduits
- Ovens and fireplaces
- Slabs or shingles for roofs
- Decorative panels and tiles
- Wall paneling
- Floors
- Telephone and power poles
- Lining for tunnels and mines
- Stakes for supporting vine crops, tomatoes, beans, etc. (for termite resistance)
- Pothole repairs (squares of ferrocement sized and laid in the hole)
- Timber-treatment enclosures
- Shutters and formwork for use in standard concrete construction

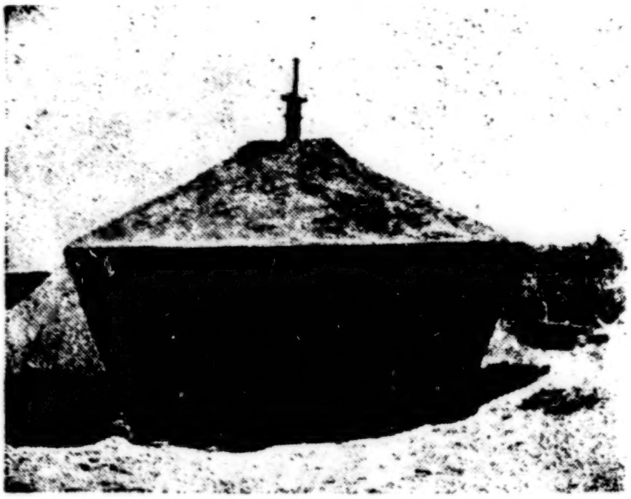


FIGURE 2 Fifty-cubic-meter ferrocement water tank used for fire-fighting in the USSR. (Grodski, E.I., and Grodek, A.B., *Ferrocement in Farming Buildings and Farming Applications.* Moscow: Gostroizdat, 1962. [In Russian])

RECOMMENDATION 2: Ferrocement for Indigenous Boats

The panel recommends ferrocement as a substitute for materials now used in the construction of traditionally shaped, indigenous boats. This application deserves widespread dissemination, a function that technical assistance agencies might well assume. The record of successful experiments confirms the technical feasibility, but field trials or demonstrations may be needed in some developing areas to overcome local resistance to innovation in boatbuilding.

The Food and Agriculture Organization of the United Nations (FAO) and the United Nations Industrial Development Organization (UNIDO) have taken the initiative in introducing ferrocement in developing countries and demonstrating its importance in a developing-country context. Thus far, however, these ferrocement-based technical assistance projects have been oriented toward larger, oceangoing trawlers with sophisticated western-style hulls, with the objective of increasing commercial fishing capability. Commercial fishing on this scale requires a considerable land-based organization to preserve, transport, and market the product, and the cost of large fishing boats represents an investment that subsistence-level fishermen cannot afford. In this report we are concerned with individual boatmen, whether commercial or subsistence, who would benefit from the low cost, long life, and easy repairs of small, familiarly shaped and familiarly propelled ferrocement boats.

Improving such craft will not initially have the same effect on economic development as introducing fishing trawlers. Yet, the ready acceptance of cheap, traditionally shaped boats could significantly affect economic development because of the much larger number of boats involved and the greatly increased life expectancy over their wooden counterparts.

Ferrocement's unique characteristics–low cost of materials, strength, ease of maintenance and repair–recommend themselves particularly to the fabrica-

tion of small, "native" craft. The usual curved displacement hulls of indigenous craft are appropriate for this material. Small ferrocement workboats can be built on site, by local (but supervised) laborers who are usually available and low cost. Because these boats are mainly hull, and therefore without costly fittings, the builder's savings are maximized. Never far from land and usually in fresh water, small workboats undergo less stress than deep-water vessels and require less stringent technology and quality control. Moreover, existing wooden craft are often so heavy that conversion to ferrocement sometimes yields boats equivalent or lighter in weight.

Since design improvements can be added incrementally, a traditionally shaped boat might, over the years, also be improved in design. In particular, the use of ferrocement allows all the complex curves of planked wooden boats, as well as the more complex curves that are not possible in wood but would improve the boat's performance.

Ferrocement is free from attack by teredos (shipworms), wood rot, and other hazards of the tropics. Furthermore, ferrocement boats are inherently strong enough to be powered; some comparable wooden boats are not strong enough to take mechanical power.

RECOMMENDATION 3: Ferrocement for Food-Storage Facilities

The panel believes that the urgent need to preserve grain and other food crops in developing countries justifies extensive field trials in the use of ferrocement for silos and storage bins. The existence of successful prototypes sug-

FIGURE 3 Ferrocement water tanks now being tested in Thailand. (Siam Cement Group, Bangkok, Thailand)

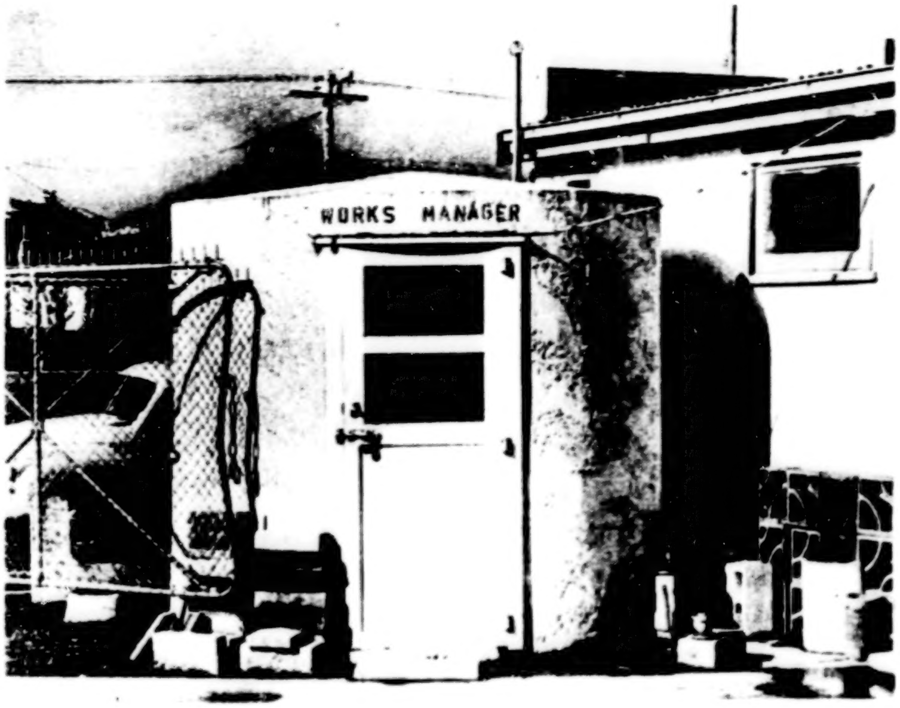


FIGURE 4 In New Zealand utility buildings such as this are made by making minor modifications during the manufacture of ferrocement water tanks. Most ferrocement tank producers make a range of ferrocement dairies, cold stores, pump rooms, and killing sheds. (New Zealand Portland Cement Association)

gests that little more research is needed, other than techno-economic and design studies for given localities.

In tropical regions, high temperatures and humidity promote the growth of mold and rot on foodstuffs, destroy moisture-sensitive materials such as bagged cement and fertilizer, and encourage thermal or ultraviolet degradation of many products. Insects, rodents, and birds also take an enormous toll. Perhaps 25 percent* of each year's food crop in the developing world is rendered unfit or unavailable for consumption because of improper handling, storage methods, and facilities.

Hundreds of ferrocement boats floating on the world's waterways demonstrate that this material is watertight, and other experience has shown that ferrocement does not readily corrode in the tropics.

Experience in Thailand and Ethiopia** has shown that ferrocement grain silos can be built on site very inexpensively, using only one supervisor and unskilled labor. A simplified version of known ferrocement boatbuilding materials and techniques was used to build the silos. Measurable losses in the

*Raymond E. Borton, ed. *Selected Readings To Accompany Getting Agriculture Moving Vol II*. New York: Agricultural Development Council, 1966. p. 672.

**See Appendices B and C.

prototype silos are less than 1 percent per annum. Rodents, birds, and insects cannot gain entrance. Since these ferrocement silos are airtight, the inside air is quickly deprived of oxygen by the respiring grain, and insects (eggs, larvae, pupae, or adults), as well as any other air-breathing organisms introduced with the grain, are destroyed.

This safe means of storing grains and other foods such as pulses and oilseeds could help farmers in the developing world to become more self-reliant, and could contribute significantly to a country's economy and food reserves.

RECOMMENDATION 4: Ferrocement in Food Technology

In view of the properties, availability, ease of manufacture, and reliability of ferrocement, the panel recommends a serious, wide-ranging effort by research organizations to investigate the use of ferrocement to replace steel—particularly stainless steel—in manufacturing at least some units of basic food-processing equipment.

Many foods—highly perishable, irreversibly affected by temperature changes and biological and chemical contaminents—are lost to mankind be-

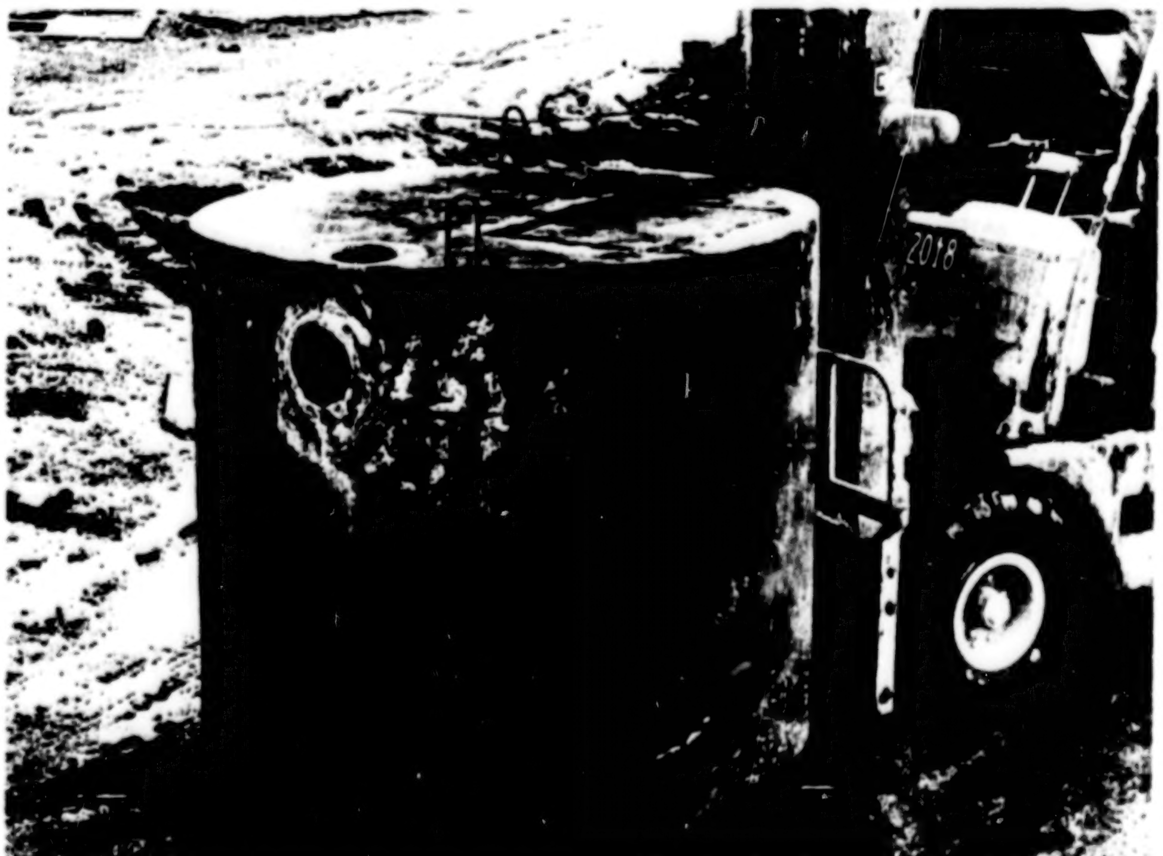


FIGURE 5 A typical ferrocement septic tank commercially available in New Zealand. (New Zealand Portland Cement Association)

cause there are no rural processing plants to preserve, convey, or process food products soon after harvest. In many developing areas, high construction costs prohibit the use of even simple manufactured equipment. These costs are largely due to the traditional use of stainless steel, expensive on any account, but especially so in terms of foreign exchange when it has to be imported.

If ferrocement food-processing equipment (perhaps with an inert surface coating) can be developed, it may improve levels of nutrition and lend itself to labor-intensive, cottage-industry food processing in developing countries.

Some advantages of ferrocement for food-processing equipment are its (1) fabrication from mainly local materials; (2) structural strength and reliability, (3) ease, economy, and versatility of construction; (4) ease of maintenance and repair; and (5) easy-to-transport raw materials.

Extensive preliminary laboratory research is needed, particularly to investigate the sanitary properties of ferrocement structures and their ability to meet other specifications for food processing. Nevertheless, the panel believes that the effort is worthwhile in view of ferrocement's apparent suitability for

- Processing of fruit and vegetables for preservation.
- Fermentation vats for fish sauces, soy sauce, beer, wine, etc.
- Storage vats or tanks for fruit juices, vegetable oil, whey, or drinking water.
- Many other purposes—spray driers for milk, driers for copra, cooking stoves or ovens, dairies, freezing chambers, and slaughterhouses.

RECOMMENDATION 5: Ferrocement for Low-Cost Roofing

The panel believes that ferrocement may prove a suitable material for low-cost roofing in developing countries. Applied-science laboratories in developing countries and technical assistance agencies should seriously consider this area for field trials and techno-economic studies.

Adequate shelter is an essential human need, and a roof is the basic element of shelter. But current materials are not meeting the need for roofs. The more-than-80 developing countries in the world suffer from housing shortages resulting from population growth, internal migration, and sometimes from war and natural disaster. For most dwellings in developing countries, a durable roof constitutes the major expense. Roofs made of cheap local materials, such as scrap metal, thatch, or earth products (sand, mud, rock), are usually unsafe and temporary. A secondary problem is the need for adequate and durable supporting structures. In some areas, scarce wooden supports are weakened by decay and insect attack.

Ferrocement represents a potential solution to roofing problems because of its relatively low cost, durability, weather-resistance, and particularly its versatility. Unlike most conventional materials, ferrocement can be easily shaped into domes, vaults, extruded type shapes, flat surfaces, or free-form areas. Because ferrocement is easily fabricated, even in rural areas, by supervised local labor using mainly indigenous materials, it seems an excellent medium for on-the-site manufacture of small or large tiles (shingles) or other roofing elements. Where wooden timbers are very expensive, ferrocement beams might be made on site to replace wooden structures used to support indigenous roof coverings. Its most economical use, however, appears to be for fairly large-span roofs.

Ferrocement is not commonly used for roofing because its promise has not generally been recognized. Its use, particularly in developing countries, must be preceded by more research and experimentation in design and production techniques suited to construction by unskilled labor.

RECOMMENDATION 6: Ferrocement in Disaster Relief

The panel recommends ferrocement for careful consideration by disaster-relief organizations. This recommendation combines all the potential applications in developing countries considered by the panel.

After fires, floods, droughts, and earthquakes, the needs for food, shelter, and public health facilities are urgent. Transportation is often disrupted by destruction of roads, bridges, boats, and airstrips. Supplies of bulky conventional building materials may be stranded outside the disaster area, whereas the basic ingredients of ferrocement may be available on the site or easily transported.

The versatility of ferrocement also reduces logistical supply problems: wire mesh, cement, sand, and water can be substituted for the metal used for roofing, woods or plastic for shelters and clinics, asphalt for helipads, steel for bridges, and so on. Moreover, most ferrocement structures, though built for an emergency, will last long after the emergency is over.

In the panel's opinion, ferrocement could be used at a disaster site for many purposes:

- Transport facilities, from simple boats to barges, docks, marinas, helipads, and simple floating bridges or short footbridges--as well as road repairs.
- Food-storage facilities, quickly designed to local needs and quickly built, to preserve emergency food supplies.
- Emergency shelters such as, for example, the quonset type of roof, which is easy to erect and highly efficient.

- Public health facilities, such as latrines and clinics, built with ferrocement roofs and stucco-type walls of the same wire mesh and mortar.

To prepare for the use of ferrocement in disaster relief, demonstrations in simulated emergencies could be arranged for national and international relief agencies; and cadres of ferrocement workers could be trained in emergency applications and the supervision of local laborers at the disaster site.

RECOMMENDATION 7: A Coordinating Committee

The panel proposes that a multidisciplinary *Committee for International Cooperation in the Research and Development of Ferrocement for Developing Nations* be established, composed of experts from countries that have achieved high competence in using ferrocement, including the Soviet Union and the People's Republic of China. The committee might be established under the auspices of such agencies as UNIDO and FAO, which already have similar groups concerned with other technologies.* No existing group is available to agencies in developing countries who seek competent advice; yet such an international committee of experts is required at least until adequate standards and safeguards for ferrocement construction** become available—particularly for deep-water uses. Such a committee could help to avoid repetition of several hapless ferrocement enterprises of the recent past.

The proposed committee should have, as a minimum, the following responsibilities:

1. To improve communication and cross-fertilization among all the areas of expertise involved (engineering, chemistry, architecture, agriculture, food science, construction, fisheries, boatbuilding);
2. To convene meetings that provide opportunities for communication among the experts and technicians; and
3. To provide direction and catalysis for the ferrocement training facilities described in Recommendation 8.

By these actions the committee could further the rational and effective introduction of ferrocement technology into developing countries and en-

*For example, the FAO's "Advisory Working Party on Hard Fibre Research" and UNIDO's various "F[illegible]. Working Groups."

**For example, the Society of Naval Architects and Marine Engineers is currently engaged in formulating specifications for the design of ferrocement craft; Lloyd's Register of Shipping and the American Bureau of Shipping have related work in progress.

courage research and development to move in an efficient and purposeful manner.

RECOMMENDATION 8: Ferrocement Training Facilities

The panel recommends that training facilities in ferrocement technology and application be established. Otherwise, the present serious shortage of trained staff to assist or advise in ferrocement construction projects may limit the establishment of high-quality programs.

The panel strongly believes that ferrocement's potential justifies the location of such facilities in, or close to, the developing world.

Two existing programs in the South Pacific deserve attention and replication. In New Zealand, the government is funding a training school for ferrocement marine construction. UNIDO has a program in Fiji in which villagers travel to a central boatbuilding yard where they work together to build a "village" boat.

The ferrocement schools proposed by the panel should

1. Train personnel from developing countries to establish water and land ferrocement construction facilities and to supervise construction projects;
2. Prepare personnel to establish country- or local-level training schools; and
3. Produce audiovisual materials.

These ferrocement training schools could be grafted onto existing technical institutions or set up as separate establishments.

RECOMMENDATION 9: An International Ferrocement Information Service

Because of rising interest in ferrocement, the panel recommends the establishment of an international service to collect and disseminate information on ferrocement science. Such a service could prevent unnecessary duplication of research and development and ensure that an interested developing country is fully informed of relevant experience with ferrocement in other parts of the world.

This service should be particularly important for fabricators of specific products who wish to know how ferrocement will work for them. Because of the diversity of industries that are potential users of ferrocement and the tendency for individual industries to build up their knowledge independently,

the availability of a centralized information service could help promote an efficient development of ferrocement technology.

The information service might well be set up at an academic or research institution already possessing competence and ongoing programs in ferrocement technology.

The information service should have at least the following functions:

1. To maintain an information bank and inquiry referral service on ferrocement;
2. To disseminate information on research and development efforts and on advances in ferrocement technology and experiences in applying it; and
3. To help developing countries identify experienced ferrocement companies and consultants, especially those with experience in developing countries.

CHAPTER II

Background Information

Ferrocement is a term commonly used to describe a steel-and-mortar composite material. Essentially a form of reinforced concrete, it exhibits behavior so different from conventional reinforced concrete in performance, strength, and potential application that it must be classed as a completely separate material. It differs from conventional reinforced concrete in that its reinforcement consists of closely spaced, multiple layers of steel mesh completely impregnated with cement mortar. Ferrocement can be formed into sections less than 1 inch thick, with only a fraction of an inch of cover over the outermost mesh layer. Conventional concrete is cast into sections several inches thick with an inch or so of concrete cover over the outermost steel rods. Ferrocement reinforcing can be assembled over a light framework into the final desired shape and mortared directly in place, even upside down, with a thick mortar paste. Conventional concrete must be cast into forms.

These fairly simple differences lead to other, more remarkable differences. Thin panels of ferrocement can be designed to levels of strain or deformation, with complete structural integrity and water tightness, far beyond limits that render conventional concrete useless. Ease of fabrication makes it possible to form compound shapes with simple techniques; with inexpensive materials; and, if necessary, unskilled (but supervised) labor.

HISTORY OF FERROCEMENT*

The most extensively used building medium in the world today is concrete and steel combined to make reinforced concrete; familiar uses are in high-rise buildings, highway bridges, and roadways. Yet, the first known example of re-

*Actually a misnomer, because the material is a form of concrete. In 1847 Lambot called it *ferciment*. Nervi's version was *ferro-cemento*.

inforced concrete was a ferrocement boat. Joseph-Louis Lambot's original French patents on wire-reinforced boats were issued in 1847 not long after the development of portland cement. (See Figures 6, 7.) This was the birth of reinforced concrete, but subsequent development differed from Lambot's concept. The technology of the period could not accommodate the time and effort needed to make mesh of thousands of wires. Instead, large rods were used to make what is now called standard reinforced concrete, and the concept of ferrocement was almost forgotten for a hundred years. Reinforced concrete developed as the material familiar today in fairly massive structures for which formwork to hold the fresh concrete in the wide gaps between reinforcing rods and a fairly thick cover over the rods nearest the surface are required.

Reinforced concrete for boatbuilding reappeared briefly during the First World War, when a shortage of steel plates forced a search for other boatbuilding materials. The U.S. and U.K. governments, among others, commissioned shipbuilders to construct seagoing concrete ships and barges, some of which continued in use after the war. The same phenomenon occurred in the United States during the Second World War. However, the conventional use of large-diameter steel rods to reinforce the concrete required thick hulls, making the vessels less practical to operate than lighter wood or steel ships.

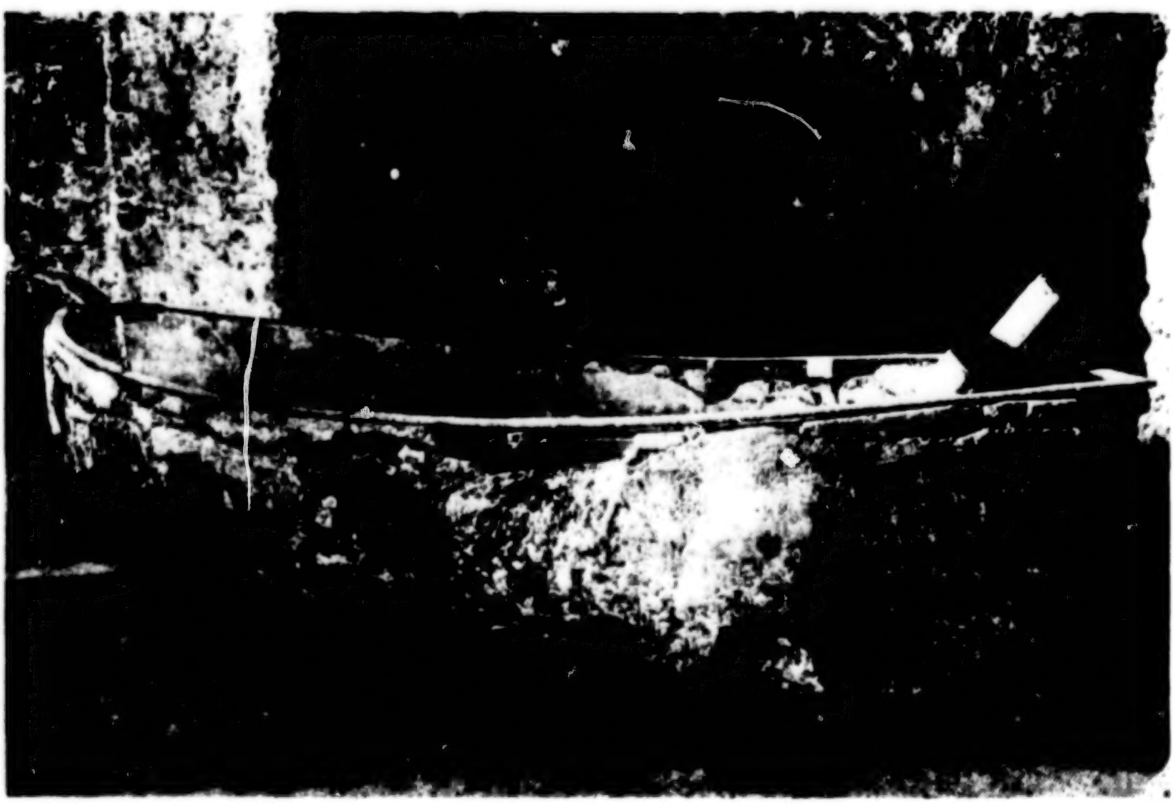


FIGURE 6 Lambot's original ferrocement boat built in 1848 now rests in the Brignoles Museum in France. (Brignoles Museum, France)

In the early 1940's, Pier Luigi Nervi resurrected the original ferrocement concept when he observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogenous material and capable of resisting high impact. Thin slabs of concrete reinforced in this manner proved to be flexible, elastic, and exceptionally strong. After the Second World War, Nervi demonstrated the utility of ferrocement as a boatbuilding material. His firm built the 165-ton motor sailer *Irene* with a ferrocement hull 1.4 inches (3.6 cms) thick, weighing 5 percent less than a comparable wood hull, and costing 40 percent less. The *Irene* proved entirely seaworthy, surviving two serious accidents. Other than simple replastering necessitated by the accidents, the hull required little maintenance.

Despite this evidence that ferrocement was an adequate and economical boatbuilding material, it gained wide acceptance only in the early 1960's in the United Kingdom, New Zealand, and Australia. In 1965, an American-owned ferrocement yacht built in New Zealand, the 53-foot *Awahnee*, circumnavigated the world without serious mishap, although it encountered 70-knot gales, collided with an iceberg, and was rammed by a steel-hulled yacht. Other ferrocement boats have shown similar practicality, and their number is steadily increasing.

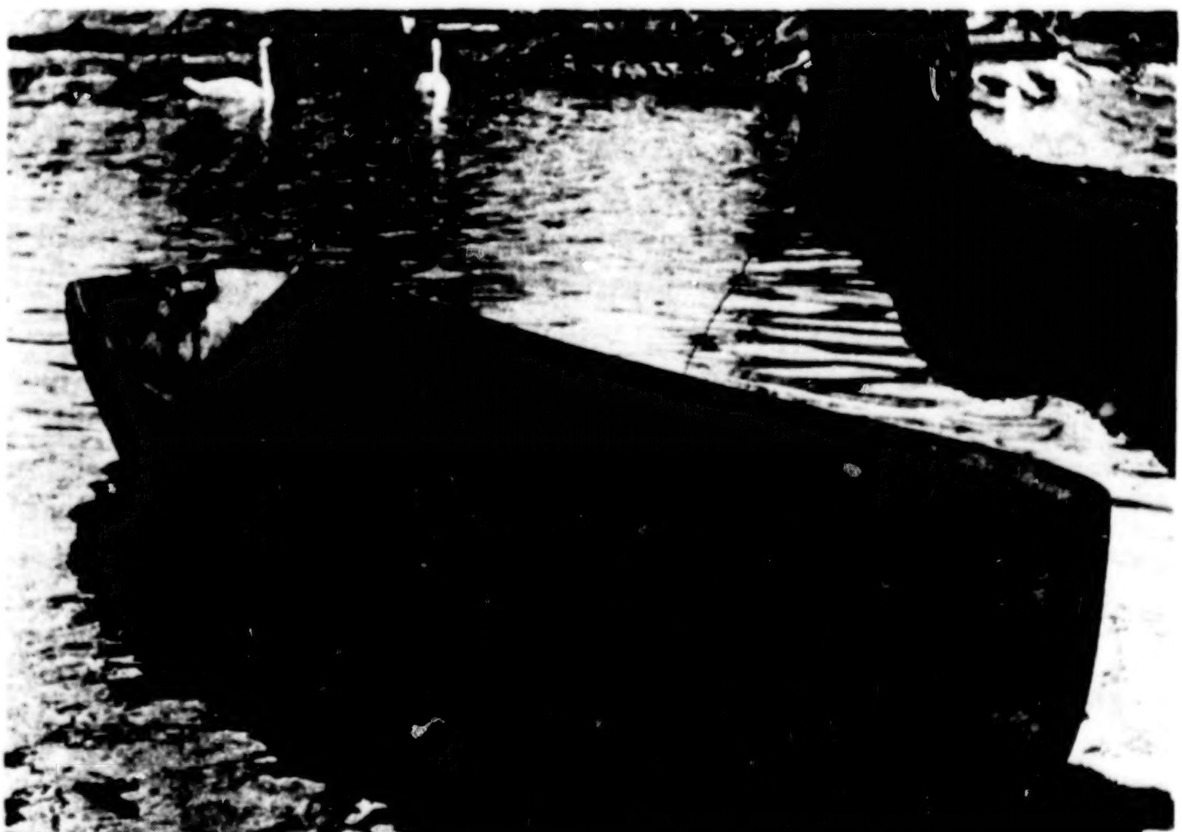


FIGURE 7 Built in 1887, this Dutch ferrocement boat was still afloat, in 1967, at the Amsterdam Zoo. (*Cement*, Amsterdam, The Netherlands)

Recent emphasis on ferrocement as a boatbuilding material has obscured Nervi's noteworthy applications to buildings. He built a small storehouse of ferrocement in 1947 (Figure 15). Later he covered the swimming pool at the Italian Naval Academy with a 50-foot vault and then the famous Turin Exhibition Hall—a roof system spanning 300 feet. In both ferrocement is one of the structural components; the ribs and outer surface are reinforced concrete (as in Figure 8).

Nervi's work and subsequent applications presage an application of ferrocement on land that may overshadow the fresh-water applications.

CHARACTERISTICS OF FERROCEMENT

Ferrocement is a high-quality structural material whose simple constituents and formation make it usable for many construction purposes in even the most underdeveloped societies. In no way an inferior product specifically for cheap uses, it is in some respects more sophisticated than prestressed concrete. Ferrocement usually uses a freestanding frame of wire mesh that is mortared in place on site. The wire mesh is formed into the desired shape (domes, simple curves, or compound curves). Supporting framework used to outline the shape can be wood, precast concrete, or a simple jig made from steel rods or pipes. These supports are usually very rudimentary and serve only to outline the shape for the layers of wire mesh to be added next. They can eventually be removed or left in place to become part of the final structure.

The economy of ferrocement construction, compared with steel, wood, or glass-fiber reinforced plastic (FRP), depends greatly on the product being built, but ferrocement is almost always competitive, particularly in tropical developing countries where steel is expensive, frequently drains foreign exchange reserves, and requires sophisticated facilities and skilled operators. FRP is much more costly, creates a fire hazard, requires advanced technology, sophisticated materials, and skilled labor; and its ingredients are sensitive to tropical temperatures. Wood is almost nonexistent in many arid or deltaic countries. Even heavily forested countries such as Indonesia, the Philippines, and Thailand foresee serious shortages due to growing demands of an increasing world population. Furthermore, in the tropics wood is subject to rot, insects, and teredos.

The relatively low unit cost of materials may be the greatest virtue of ferrocement. Worldwide, the costs of sand, cement, and wire mesh vary somewhat; but the greatest variable in construction costs is the unit cost of labor. In countries with high-cost labor, the economics of ferrocement often make it noncompetitive. But, according to UNIDO,

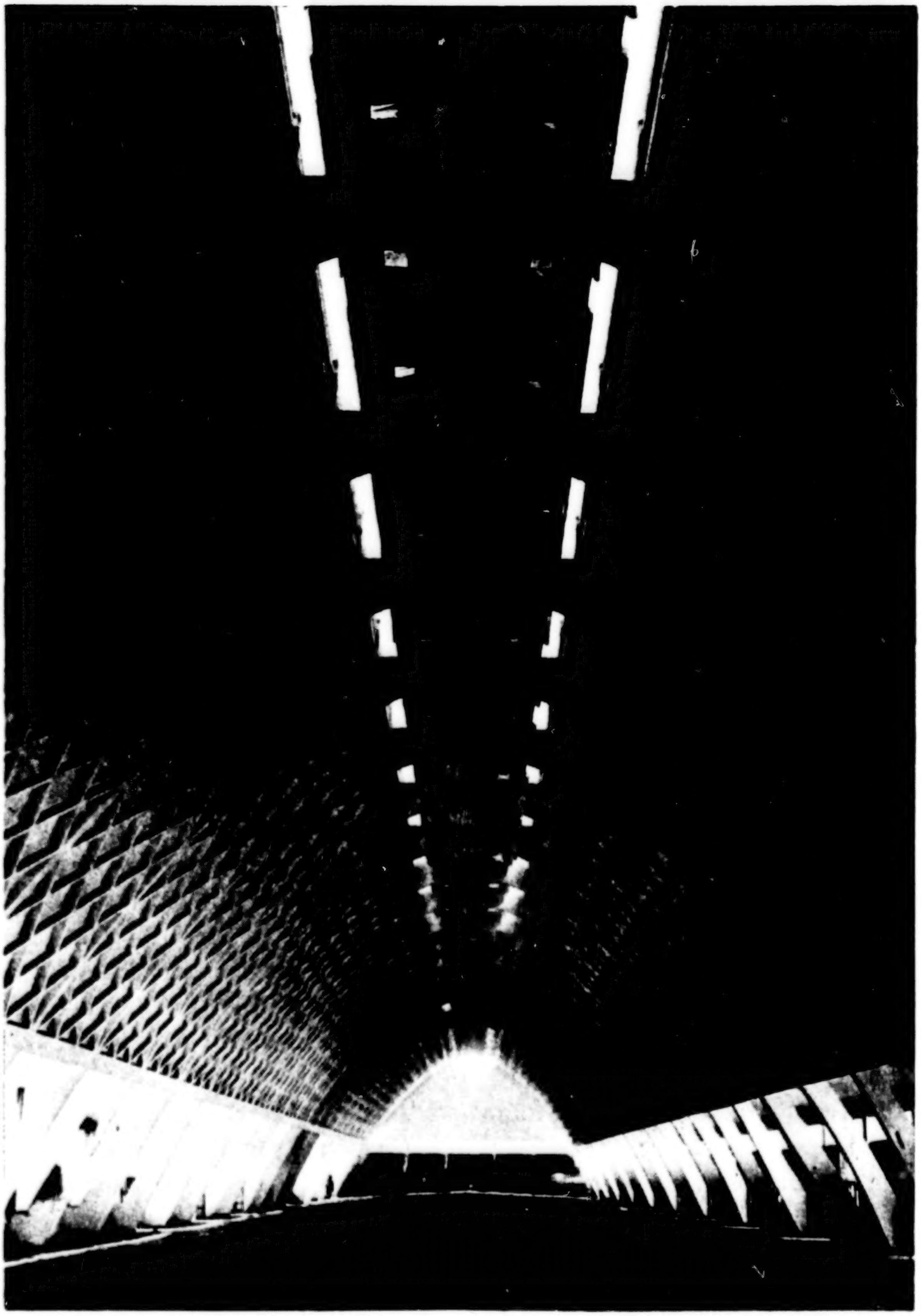


FIGURE 8 Nervi's warehouse (1950-51) in Tortona, Italy, for storing salt. Patterned ferrocement surface is structurally in collaboration with reinforced-concrete ribs and outer surface. Ferrocement has been used in the construction of domes and roofs over stadiums, opera houses, restaurants, but such applications are less relevant to urgent needs of most developing countries. (Studio Nervi, Rome)

. . . experience has shown that where unskilled, low-cost labour is available and can be trained, and as long as a standard type of construction is adhered to, the efficiency of the labour will improve considerably, resulting in a reduced unit cost. Under these conditions, ferrocement compares more than favourably with other materials used in boatbuilding, such as timber, steel, aluminum or fibreglass, all of which have a higher unit material cost and require greater inputs of skilled labour.*

SUITABILITY TO DEVELOPING COUNTRIES

Although the increased interest in ferrocement for water and land use is fairly recent, successful examples of innovative applications, within a wide range of construction techniques and sophistication, already promise a major impact on developing countries for the following reasons:

1. Ferrocement may be fabricated into almost any conceivable form to meet the particular requirements of the user. This is particularly pertinent where acceptance of new materials may be dependent on their ability to reproduce traditional designs.
2. The basic raw materials for the construction of ferrocement—sand, cement, and reinforcing mesh—are readily available in most countries. Sand and cement are used in building and road construction, and mesh is used in agriculture (chicken netting) and housing construction (plastering lath).
3. Except for highly stressed or critical structures such as deep-water vessels, adequate ferrocement construction does not demand stringent specifications. A wide range of meshes can be used; both hexagonal and square meshes have produced successful structures. The cement is of standard quality used in building construction. Special grades are unnecessary.
4. Little new training is required for the laborers, providing a skilled supervisor is on hand. Cement construction techniques are widely known in developing countries, and indigenous construction workers often show a good aptitude for plastering. (See Figures 9, 10.)
5. Transportation, logistics, and materials-handling are serious problems in developing countries, and ferrocement construction simplifies each one. Sand and water can usually be obtained in the region of the building site; and the quantity of cement normally required can be easily transported. Only the wire mesh may require transportation from distant production centers. Under extremely difficult conditions (such as in the roadless highlands of Nepal), wire mesh may be handloomed on site from reels of straight wire, a technique apparently already in use in rural areas of the People's Republic of China.

*UNIDO. *Boats from Ferro-Cement.* Utilization of Shipbuilding and Repair Facilities, Series No. 1. United Nations, N.Y.: 1972. p. 5.

FIGURE 9 A paste of mortar is forced into the layers of mesh by hand . . . (Smith Kampempool, Applied Scientific Research Corporation of Thailand)

FIGURE 10 . . . or trowel. The mortar is dry enough to remain in place when applied; a formwork is not needed. (Noel D. Vietmeyer, National Academy of Sciences)

(See Appendix A.) For simple, indigenous-type boat hulls and agricultural or construction uses, no well-developed or centralized building site is required (though it is an option for a builder). Construction can well be done on site at the riverbank, in the village, high in the mountains, or wherever needed.

6. Ferrocement withstands severe abuse. Authenticated reports tell of boat hulls wrecked on reefs and successfully surviving savage poundings. Afterwards, the ferrocement was easily and rapidly repaired on site. Only simple tools are needed to repair any damage to the mesh and only cement and sand to make a fresh mortar. Such repairs are usually good for the remaining life of most ferrocement products, though the more stringent requirements of deep-water boats may dictate that the repair be reworked by skilled labor.

This report explores these advantages in land and water uses, and summarizes the basic material properties of ferrocement. Appendices contain descriptions of specific applications.

CHAPTER *III*

Ferrocement for Boatbuilding

Ferrocement boats have been built and are now operating in, among other places, India, Ceylon, Uganda, Dahomey, New Guinea, Thailand, Samoa, New Caledonia, Fiji, Hong Kong, the Philippines, Cuba, Ecuador, the People's Republic of China, South Vietnam, Iran, Egypt, Brazil, and the Bahamas. This steady growth in application in developing countries constantly adds to our understanding of ferrocement's unusual properties and how this thin shell of highly reinforced cement can provide a surprisingly strong, yet simply fabricated boatbuilding material.

Boatbuilding applications of ferrocement can contribute to economic development and the general welfare of people in developing countries, particularly as quality timber suitable for boats becomes scarce because of housing and other demands from rapidly increasing populations. Moreover, quality timber often has a limited life: in tropical water teredos attack it, and in many coastal but arid regions (as the Red Sea region) the drying action of the sun seriously affects wooden craft pulled up on the beach. Accordingly, many boats last such a short time that owners are continually in debt—they cannot repay the initial loan before they need new loans to replace worn-out boats.

Of the two general types of ferrocement boatbuilding, one has been practiced in a good many countries around the world, and the other has found typical application in the People's Republic of China. The first involves western-style craft with hulls built with state-of-the-art technology for *deep-water* fishing or recreation. Often as complicated as other boatbuilding methods, this type of construction requires some skilled labor, is relatively expensive, and in developing countries is mainly suited to equipped shipyards. Experience with this approach goes back a decade. Typical examples are FAO projects in Thailand* and Uganda, UNIDO projects in Fiji, and the

*J. Fyson. "Construction of a 16-metre Ferro-Cement Fishing Boat." FAO Fisheries Technical Paper No. 95. Rome, 1970.

commercial construction of fishing vessels in Hong Kong. The panel recommends that developing countries enter ferrocement programs for such *ocean-going* ferrocement boats only with expert supervision, with extreme emphasis on quality control, and in a well-equipped boatyard. Under these conditions, craft can be made that contribute significantly to deep-water fisheries development.*

FERROCEMENT FOR CRAFT OF LOCAL DESIGN

The second type of ferrocement application is the construction of simple, indigenous hulls designed for smooth-water use, such as the ferrocement sampans built by the thousands in the People's Republic of China. In Appendix A, these Chinese techniques are discussed, and photographs show clearly the unsophisticated conditions in which a rural commune produces fairly large and very satisfactory boats at a rate of about one per day. This experience demonstrates that unlike deep-water craft, these ferrocement boats can be built with confidence within the lesser standards attainable in rural areas of a nonindustrialized country.

Indigenous workboats (such as sampans, dugout canoes, dhows, and the type of craft used on the Ganges, Nile, Zaire [Congo], and Mekong Rivers) with curved hulls 25-60 feet long are ideally suited to ferrocement's unique characteristics and take best advantage of them. Ferrocement derives great strength in curved shapes. The lack of design specifications–a worry of naval architects now working on deep-water vessels–is relatively unimportant for these craft. They require less stringent technology and quality control because they undergo far less stress and danger than deep-water vessels.

Indigenous boats are mainly hull, which allows ferrocement's cost savings to be maximized for the builder. (In a western-style boat internal fittings often account for a high percentage of costs; any saving on the hull is a small part of the total cost.) Indigenous-style boats are best built locally, by the usually available and low-cost labor supervised by a trained technician.

Indigenous craft are often unpowered, at least by an internal engine, so questions of adequate hull support for drive-shaft vibration (the lack of which caused one celebrated ferrocement failure in a developing country) are irrelevant. Yet, the boats can easily be powered externally, an important advantage where existing wooden boats are too frail to take power (as in the Ganges Delta).

*For more information on western-style craft, see UNIDO. *Boats from Ferrocement.* Utilization of Shipbuilding and Repair Facilities, Series No. 1. Sales No.: E. 72. II. B. 23. United Nations, N.Y., 1972. $U.S. 2.00.

Several panelists felt that the use of "long-tailed," powerpole, outboard engines should be explored in development programs for simple ferrocement hulls. Such engines are used by the thousands in Thailand because of their simplicity, lightness, and versatility.

Ferrocement, with its adaptability to curves, may improve local designs by allowing the corners required by the current plank construction to be smoothed out.

Weight is not a major factor in the displacement-type hulls of indigenous-styled boats, although they are often already so heavy that conversion to ferrocement may yield craft equivalent or lighter in weight.

BUILDING A FERROCEMENT BOAT

In industrialized countries many ferrocement boats are built in backyards far from water, but in developing countries building sites will probably be at the water's edge because of transportation difficulties. A waterfront location should be chosen with the size of craft, its draft, and its launching clearly in mind.

Although the site must be accessible for delivery of construction material, it can be located far from commercial harbors because needed equipment and tools are portable. Cement and wire mesh, as normally packed for shipping, seldom dictate choice of a site, but availability of sand may be important in areas where bulk transport is particularly difficult. Electricity may be desirable in some cases, but is not necessary. A shelter will be required to protect unused cement and improve working conditions in rainy areas. In river and coastal regions, where the need for boats may be very scattered, or in areas where flooding and terrain changes make a single building site less practical, the entire production facility could be located on a barge capable of moving to all sites, or of moving with fluctuating flood levels.

There are five fundamental steps in ferrocement boat construction:

1. The shape is outlined by a framing system.
2. Layers of wire mesh and reinforcing rod are laid over the framing system and tightly bound together.
3. The mortar is plastered into the layers of mesh and rod.
4. The structure is kept damp to cure.
5. The framing system is removed (though sometimes it is designed to remain as an internal support).

Where scaffolding equipment is not readily available, the hull may be built in an inverted, or upside-down, position, resting on a suitable base (see Appen-

dix A). There are several ways to form the shape of a boat. One can build a rough wooden boat first, or use an existing, perhaps derelict, boat. In another method, pipes or steel rods frame the shape of the hull. A third way is exemplified by the construction of Chinese sampans (described in Appendix A): a series of frames (welded steel in this case) and bulkheads (precast in ferrocement) are erected to shape the hull. Layers of mesh are then firmly bound to the frames, which are left in place to give rigidity to the final hull.

Recent methods for outlining the hull's shape include using thin strips of wood to which the mesh and rod are stapled and which remain inside the final concrete structure. Other innovations include plastering the outside of the hull first and finishing the inside a day or two later after the frames, or supports, have been removed.

BOAT SIZE

Ferrocement boats from 25 to 60 feet long have been built to operate successfully. Above and below this range, ferrocement has not yet been used long enough for the panel to class it markedly superior in all respects to alternative materials. Yet the need to build craft less than 25 feet long from cheaper and longer-lasting materials is great because many such small craft are used in developing countries. Most important for river use in certain countries, they often provide a major means of personal transport (in the Ganges Delta and Mekong Basin, for instance).

Some small craft have been built, and some U.S. university engineering schools have competed in ferrocement-canoe-building contests and races. These isolated examples suggest that further development work could make ferrocement boats in the less-than-25-foot range practical, as well as competitive with wood, fiberglass (FRP), and metal boats.

The panel believes that developing country laboratories interested in research into ferrocement application will find challenge in concentrating on methods to produce suitable small craft. Research is also needed at the other extreme, for hull lengths over 60 feet, but this job should not be tackled without adequate facilities.

QUALITY CONTROL

Ferrocement, like conventional boatbuilding materials such as steel, aluminum, or FRP, benefits by good specifications and quality control. At each step of assembly, careful inspection should ensure a product quality consistent with its expected use. Inspection procedures deal mainly with common-sense issues and are primarily visual.

In countries proposing to engage in significant ferrocement boatbuilding activities it would be desirable for appropriate laboratories to evaluate the

basic raw materials at hand: cement, sand, and water—by district if necessary. Test panels should be made to determine their properties and to establish guidelines for appropriate mixes.

Ferrocement boatbuilding supervisors should maintain a continuing quality-control program. This vital factor is one potential source of weakness in the use of ferrocement for building deep-water vessels, since workmen in developing countries may have neither an understanding of, nor a concern for, specifications and quality control. It is to teach supervisors the principles of ferrocement quality control, among other things, that the training institutions suggested in Recommendation 8 are required.

When mortar is forced through the many layers of mesh used on a deep-water boat, it is difficult to ensure complete and uniform penetration. Some construction methods aggravate this difficulty more than others. Because of this problem, boats have been built with unsuspected air holes within the ferrocement; the resulting voids cause weak points in the hull, especially if water enters and corrodes the mesh. If necessary, hulls can be drilled to find voids and then grouted (filled with more mortar). Proper application technique and adequate quality control, however, will ensure that good mortar penetration takes place. A simple vibratory tool, such as an orbital sander, usually solves most of the problem. Corrosion seldom occurs if adequate mortar cover is maintained over the reinforcement.

However, as previously suggested, the degree to which these factors are important depends upon the expected use of the vessel.

CAUTIONS ON FERROCEMENT FOR DEEP-WATER CRAFT

The panel concentrated on simple craft for inland waterways of developing countries because in this situation current ferrocement technology can be utilized with confidence, despite the many differences of available skills, boat design, climate, etc., among countries. However, ferrocement boatbuilding in technically advanced countries has, so far, emphasized pleasure craft and trawlers designed for *deep-water* use, and the panel feels a responsibility to reiterate the warning to developing countries that more caution is needed when they consider ferrocement for these craft.

Ferrocement meets its ultimate test at sea: the stresses are large and unpredictable, and human lives are at stake. Boat design is not a precise science, and a pressing worldwide need exists for adequate structural-design information. This need applies to other materials, but ferrocement is less widely known or understood. Because its very nature requires combinations of constituent materials, quality control is important, but the development of ferrocement has been pushed forward largely by innovative amateurs who little understood the material and, sometimes, boat design. Only now is the

engineering community beginning to investigate ferrocement as a boatbuilding material. Detailed specifications and standards are still at an early stage of formulation.

Successful ocean-going boats and marine structures *can* be built, and have been by the hundreds. Some ferrocement boats have survived extremely rough treatment, but there have also been striking failures. In developed countries, some commercial ferrocement boatbuilding ventures have been overpromoted and have gone into bankruptcy. The panel recommends that developing countries planning to construct ferrocement trawlers and other deep-water craft should exercise great care in selecting boat designs and ferrocement expertise at this time. They should carefully investigate any company proposing to establish local operations, inquiring into the number of boats it has built, and the professional background of the company's staff (see Recommendation 9).

Ferrocement's weakest feature, compared to wood or steel, in deep-water boats is its lessened resistance to penetration by a sharp object. This penetration is called "punching" to separate it from "impact" in which a broad surface area is struck and to which ferrocement is quite resistant. Small holes can be quickly repaired, but when punching is likely to be a serious problem, some sort of surface protection might be added, or the steel content of the ferrocement could be increased.

These cautions do not contradict earlier statements on the simplicity of ferrocement construction; they stress only that techniques of design and construction are new and that for deep-water boats they must meet very stringent requirements.

OTHER APPLICATIONS ON WATER

Ferrocement could be used in the construction of floating wharfs, which can be placed (or built) in any location, thus providing access to otherwise inaccessible coastal or river areas. Tugboats seem to be ideal craft for ferrocement construction because they are heavy and highly fendered. Barges are also important applications for ferrocement, particularly the ark-shaped lighters used widely in Southeast Asia, Africa, and Latin America. Flat-sided, flat-bottomed barges are less adaptable, but an apparently successful one is operating in Thailand, carrying cement on the Chao Phya River. Reinforced concrete barges (with reinforcing rods rather than mesh and with walls several inches thick) have been operating successfully for many years in Hawaii, the Philippines, and New Zealand.

Developing countries might also take advantage of their labor resources to

construct high-quality, western-style, deep-water pleasure craft for export to North America and Europe.

Other structures on water are adaptable to ferrocement construction in developing countries. They are listed below to suggest the possibilities.

- Buoys
- Docks, including floating dry docks
- Floating breakwaters
- Houseboats
- Pontoons
- Submarine structures
- Floating and submerged oil reservoirs*
- Offshore tanker terminals*
- Floating bridges*
- Floating shelters for suitable flood-prone areas (e.g., Bangladesh)

*Hybrid structures of ferrocement and conventional concrete.

CHAPTER *IV*

Ferrocement for Food-Storage Facilities

The problem of food storage in the developing countries is emerging as a major subject of attention from technical assistance organizations. Increasing supplies of food grains, such as rice, wheat, and maize, resulting from the Green Revolution have caused an unprecedented need for grain storage in developing countries, yet most production areas are still unprepared to store this new abundance adequately. Figures in the order of 25 percent indicate how much grain is lost to inadequate harvest and inadequate storage facilities and practices. In addition to grain storage, facilities are urgently needed to protect all products sensitive to temperature, humidity, rain, wind, pest animals, bacteria, or fungi. Other typical products requiring storage are peas and beans; oil crops such as peanuts and soybeans; salt; drinking water; and related nonfood items such as fertilizers, pesticides, and cement. Major needs are small-scale silos, particularly for on-farm storage.

A particular advantage of ferrocement in building food-storage facilities in developing countries is its adaptability to an almost unlimited range of curved shapes and local conditions. Ferrocement silos require little maintenance, and they offer protection against rodents, birds, insects, water, and weather. Ferrocement is watertight, and, with appropriate sealants, it can also become airtight (see Appendices B and C). In an airtight ferrocement bin, respiration of grain, or similar products, quickly removes oxygen from the atmosphere inside and replaces it with carbon dioxide.* Any insects (adults, larvae, pupae, or eggs) or aerobic microorganisms present cannot survive to damage the stored product. No fumigation is needed. Hermetic storage of

*R. B. L. Smith *et al*. "Hermetic Storage of Rice for Thai Farmers." *Thai J. Agr. Sci.* 4, July 1971. pp. 143–155.

this kind is "particularly suitable in the tropics for the storage of dry grain."*

Methods developed for ferrocement boatbuilding can be applied to storage facilities to yield a structure of high quality. Ferrocement silos could be built in a factory, but they are particularly adaptable to on-site construction, an important consideration in remote areas without even vehicular access. As with other applications, silos require only simple artisan skills, performed by local labor with minimal supervision. In Thailand, workmen with experience acquired in the construction of a single silo have been able to supervise unskilled laborers. In many developing areas, building a food-storage facility with ferrocement is not very different from building a traditional one. In principle, the wire mesh is a substitute for bamboo or wattle mesh, and the cement mortar is a substitute for mud. Indeed, bamboo, instead of wire mesh, reinforcement might be technologically feasible if care is taken to avoid delamination caused by expansion of bamboo when it absorbs moisture.

Ferrocement can be considered for silos with curved walls, in sizes to hold 1-30 tons of grain or more. The base can be continuous with the walls, making a strong, monolithic construction (as in ferrocement boats) to prevent foundation failures and moisture damage from floods or a high watertable in the soil. Silos can be easily sealed against air or water vapor with a rubber- or bitumen-based paint.

Appendix B contains photographs of ferrocement silos developed and tested by a government research institute in Thailand for the special needs of a humid, tropical country. Bins with capacities of 4-10 tons all have sloped walls of the same height, with base and top diameters that vary in size. For larger capacity, the Thais built clusters of bins, though larger bins and connected side-by-side modifications are under consideration. Clusters have the advantage that only one bin at a time need be opened to withdraw the product while the low-oxygen atmosphere is maintained in the others. (See also Figure 11.)

In contrast to the above-ground Thai silo, an underground ferrocement storage unit has been developed in Ethiopia to replace the traditional unlined storage pits (see Appendix C). Also, it is reported that a similar underground storage system "has gained wide acceptance in Latin America where several millions of tons of produce are stored in these hermetic underground pits.**

Where grain and similar food crops can be stored with confidence, banks can lend money for construction of silos, using the crop as mortgage collateral. Traditionally, farmers borrow money (often at high interest rates) to plant their crops, then sell the product at harvest time—when its price is lowest—to

*D. W. Hall. *Handling and Storage of Food Grains in Tropical and Subtropical Countries*. Rome: Food and Agriculture Organization of the U.N., 1970. p. 181.

**D. W. Hall. *ibid*. p. 182.

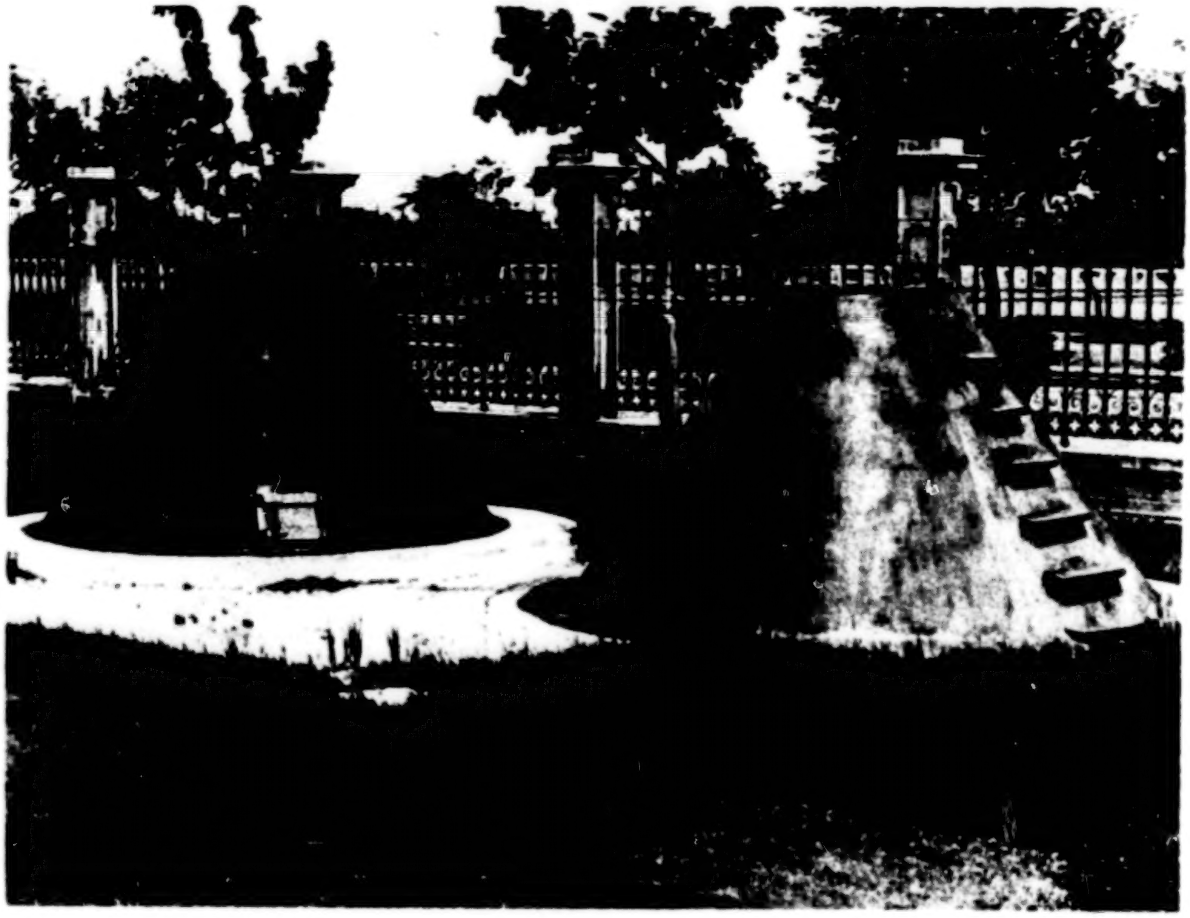


FIGURE 11 Ferrocement silos made in Thailand, showing an unloading hatch and an optional built-in ladder. (Siam Cement Group, Thailand)

pay their debts. A silo that enables a farmer to store his harvest gives him the opportunity to sell in the off-season, usually 4–6 months after harvest, when prices may increase 40–100 percent. The farmer can also store bulk food and seed for his family's needs without the loss he faces by using traditional methods.

Appendix D describes a well-developed industry in New Zealand, building water-storage tanks of ferrocement. Figures 8 and 15 show other food-storage applications.

CHAPTER *V*

Ferrocement for Food-Processing Equipment

During the panel's deliberations on food-storage facilities, the more inclusive category of food-processing equipment as a whole emerged as an exciting possibility for ferrocement application. New to the panelists, the idea has not, to their knowledge, been studied at all in developing countries—and only slightly studied elsewhere. Though data are lacking, the subject is included in this report because the panel considers it a potentially profitable area for research.

The world food problem is caused in part by poor distribution and protection of available foodstuffs in developing countries. Most foods, especially in a raw, unprocessed state, are highly perishable; they are irreversibly affected by temperature changes and, especially, by even trace amounts of biological and chemical contaminants. All these problems are most severe in tropical climates. So, in developing countries much of the food yield deteriorates soon after harvesting because processing plants to preserve food are lacking in rural areas. Excessive costs, the absence of a suitable construction material, and lack of skilled labor prohibit the manufacture of even simple, conventional processing equipment designed to store, convey, and process bulk quantities of complex natural raw materials and their derivatives.

That most food-processing equipment is large, heavy, and awkwardly shaped constrains regions where transportation is difficult and expensive. The general lack of foreign currency in developing countries makes it difficult to pay for this equipment, which is made of steel, copper, and other metals often available only from industrialized countries.

The use of ferrocement, even on a modest scale, could influence the creation or expansion of food industries in developing countries and contribute to the improved nutrition of the inhabitants. Where transportation is diffi-

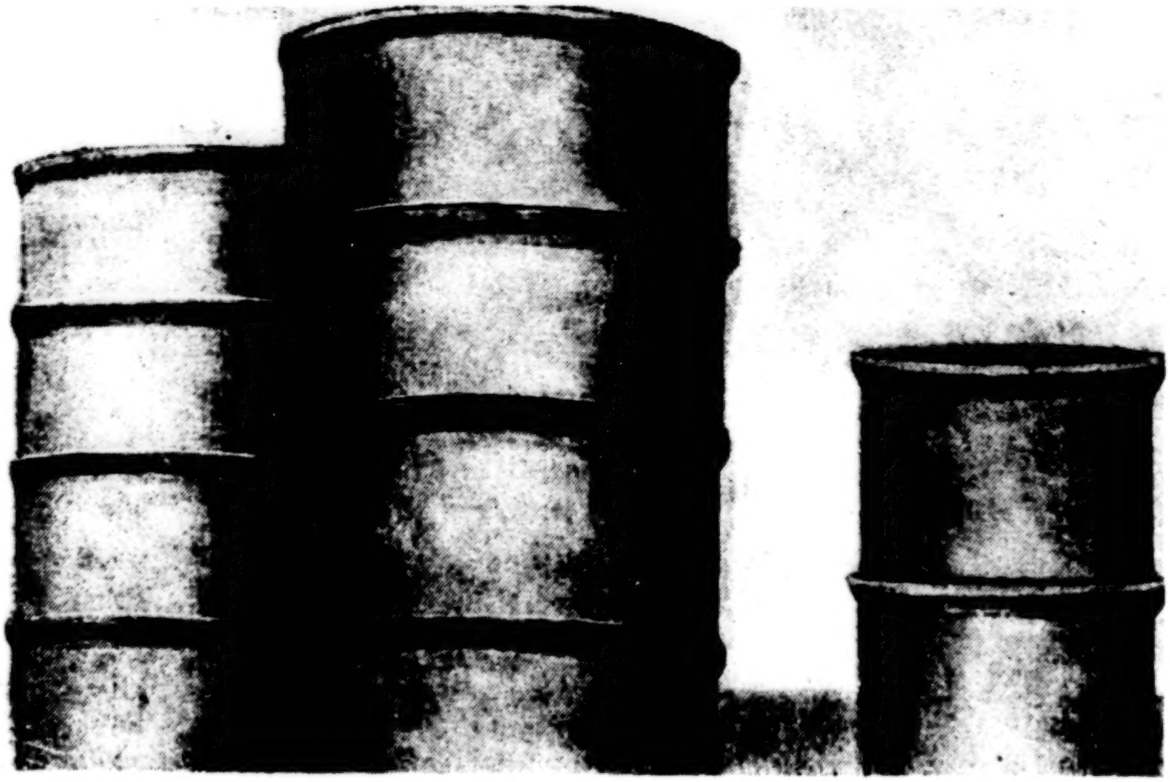


FIGURE 12 Ferrocement wine-storage tanks in the USSR. (Grodski, E.I., and Grodek, A.B., *Ferrocement in Farming Buildings and Farming Applications.* Moscow: Gostroizdat, 1962. [In Russian])

cult, ferrocement equipment can be manufactured and erected on site, by local labor, and with easily transported ingredients. It requires little foreign currency, and is uniquely suited to the fabrication of large, heavy, awkwardly shaped shell structures. It can be as strong and structurally rigid as the structures it imitates.

Extensive preliminary laboratory research is needed, particularly into the interface between a ferrocement surface and the foodstuffs it touches. This surface must be made extremely smooth, dense, and hard (for example, by techniques of multiple trowelling during the setting period). The use of coatings should be explored, such as stainless-steel foil bonded to the surface.

In addition, research must answer these questions:

- What is ferrocement's ability to meet local sanitary requirements? What methods can be used for cleaning and sterilizing?
- What are its pressure and thermal tolerances (heat transfer, thermal expansion)?
- What is the moisture-vapor transmission rate (particularly important for low-temperature applications)?

Nevertheless, a serious, large-scale effort is justified to investigate the use of ferrocement to replace steel for the manufacture of at least some basic food-processing equipment, e.g., tanks (see Figure 12), vats, pipes, trays, drying tables, cold stores and freezing chambers,* ovens, waste-product sewage treatment facilities, butchering facilities,* and dairies.*

*See Appendix D.

CHAPTER *VI*

Ferrocement for Low-Cost Roofing

Rapid population growth and industrial development have created overwhelming demands on human settlements. A still greater burden will fall on cities, towns, and rural communities in the future. According to a recent U.N. estimate, the world population will double by the year 2000 to nearly 7 billion people,* while the world urban population will increase to more than 3 billion, or 51 percent of the total world population. The size of future housing requirements alone is staggering: during 1970–1980, Asia, Africa, and Latin America will need housing for 325 million people entering urban areas, at the rate of 90,000 people per day.** And these figures do not include the vast number of rural dwellings and new or modernized work places and public facilities that will be needed.

Developing countries already have acute housing shortages because of rapid population growth and, sometimes, disasters. Typical examples are Ceylon, 200,000 houses short; India, 11.9 million; Philippines, 3 million; Republic of (South) Korea, 1 million houses short in 1970 with demand continuing to grow at over 100,000 houses per year.†

To these needs for basic housing to accommodate population increases and to improve housing quality must be added the periodic necessity to replace housing destroyed by natural disasters prevalent in the developing world. Earthquakes, typhoons, hurricanes, cyclones, floods, and fire take a vicious

*"Man's Population Predicament." *Population Bulletin*, XXVI. April 1971. p. 5.

**United Nations Advisory Committee on the Application of Science and Technology to Development for the Second United Nations Development Decade. *World Plan of Action for the Application of Science and Technology to Development*. United Nations, N.Y., 1971. p. 214.

†Sazanami, Hidehilco. "Housing." *Encyclopedia Britannica*, 1972 ed. Vol. II. p. 770.

toll of tens of thousands of dwellings each year, as in Bangladesh, Peru, and Nicaragua.

Of the desperately needed new materials and construction methods, the most critical component is appropriate roofing. Under normal conditions in developing countries the roof of a dwelling structure constitutes the major expense, often as much as 60 percent of the total cost. For most people a long-lasting roof is too expensive. Yet, most roofs manufactured from cheaper local materials such as grass or reeds (thatch) or earth products (sand, mud, rock) are short-lived and dangerous in an earthquake, flood, or fire. Thatch is notorious for harboring vermin and insects. Furthermore, an adequate roof covering is often impractical because it needs a high-cost supporting structure. For instance, tiles make excellent roofs, but they are so heavy they require extensive supporting frames. In many regions, wooden supports decay rapidly, though the covering remains sound.

To satisfy their shelter needs, many developing countries expend scarce foreign exchange for galvanized iron and other metal roofings from industrialized countries. However purchased, bulky metal sheets are expensive to transport within a country. In hot climates the heat absorption of metal roofs converts homes into ovens. Corrosion is also a problem, particularly where the metal is exposed to saltwater spray.

The previously described advantages of ferrocement for developing countries apply to roofing. Ferrocement appears to have decided advantages over several other roofing materials and could well play a major role in housing construction in developing countries. (See Figures 13-15.)

Ferrocement roofing materials can be factory mass-produced in prefabricated form, a process best suited to the concentrated demand of urban areas. Though it might be more economical to mass-produce roofing in an urban factory and truck it to a rural area (should trucking be possible), ferrocement is also easily fabricated on site in rural areas, using local labor and materials.

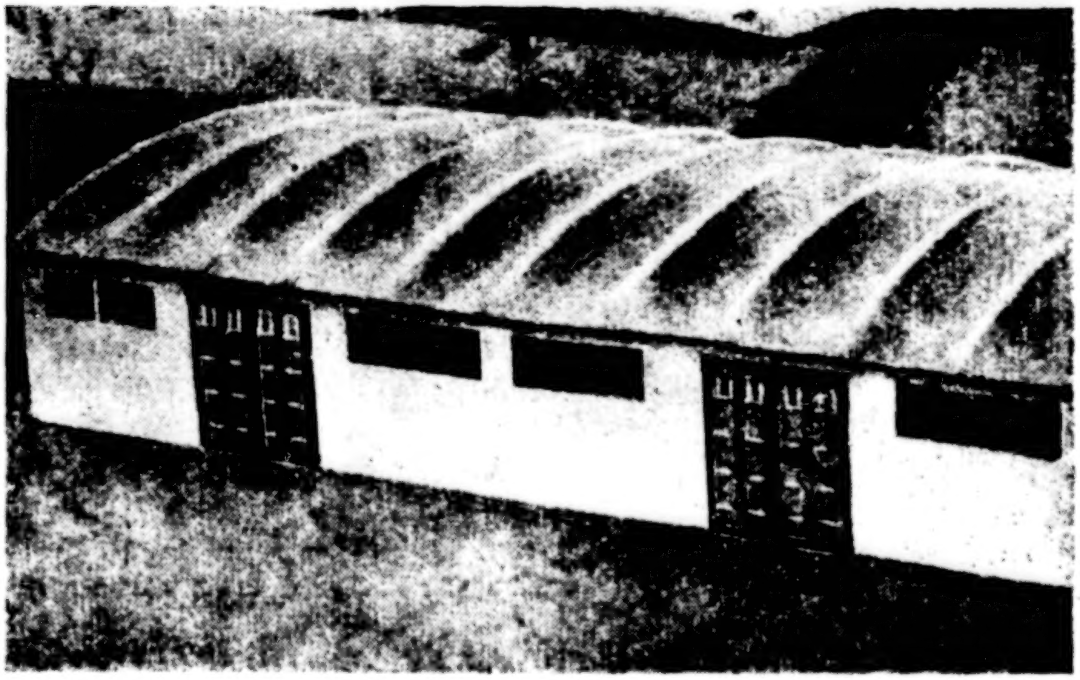
Freer in concept and makeup than most conventional roofing, ferrocement can be shaped into domes, vaults, extruded shapes, flat surfaces, or free-form areas.

Before ferrocement can be used widely for roofing, research and experiments will be required to determine the shapes and types of roofing members to be manufactured, and to explore designs and methods for anchoring and bolting these various shapes to supporting walls.

After this research and experimentation is completed, on-the-job training centers may be required to introduce the new material and its new building techniques. Preferably, these centers should also offer programs dealing with other ferrocement applications.

Research efforts to find ferrocement modifications that prove less expensive or easier to manufacture are highly recommended. Possibly, for example,

ferrocement can be sandwiched on two sides of a core of foam concrete or other lightweight material to make a less expensive and lightweight, yet still structurally strong, material.



FIGURES 13, 14 Ferrocement roofs on a farm shed and on a barn in the USSR. (*Ibid.*)

FIGURE 15 Ferrocement storehouse built in Rome in 1945 by Nervi. External ferrocement wall is 1 and 1/16th inches thick. Walls and roof are corrugated to increase stiffness. (Studio Nervi, Rome)

CHAPTER *VII*

Ferrocement Materials Technology

A working definition of *ferrocement* is "a thin shell of highly reinforced portland cement mortar." Generally, ferrocement shells range from 1/2 inch to 2 inches in thickness, and the reinforcement consists of layers of steel mesh, usually with steel reinforcing bars sandwiched midway between. The resulting shell or panel of mesh is impregnated with a very rich (high ratio of cement to sand) portland cement mortar. (Other hydraulic cements may also be used.)

Specifications of ferrocement technology range widely according to use—from oceangoing vessels in which human lives are totally dependent on the material, to small, expendable household items. Although this chapter deals with ferrocement materials science in general, in practice the quality of the ferrocement used must be matched with the end use of the product.

REINFORCING MESH

Many different kinds of reinforcing mesh will produce successful ferrocement structures. (See Figures 16, 17.) A general requirement is flexibility. Shapes with tight curves need more flexible meshes. Chicken wire, the cheapest and easiest to use, is adequate for the structural requirements of most boats in developing countries and for all uses on land. It is not the most recommended mesh for high-performance structures, such as deep-water marine hulls.

The wire mesh could be woven on site from coils of straight wire, giving a local engineer greater opportunity to adapt the mesh size and wire diameter to any given job. Because wire coils are less bulky than mesh, this method might also save considerably on transportation costs (both ocean shipping and

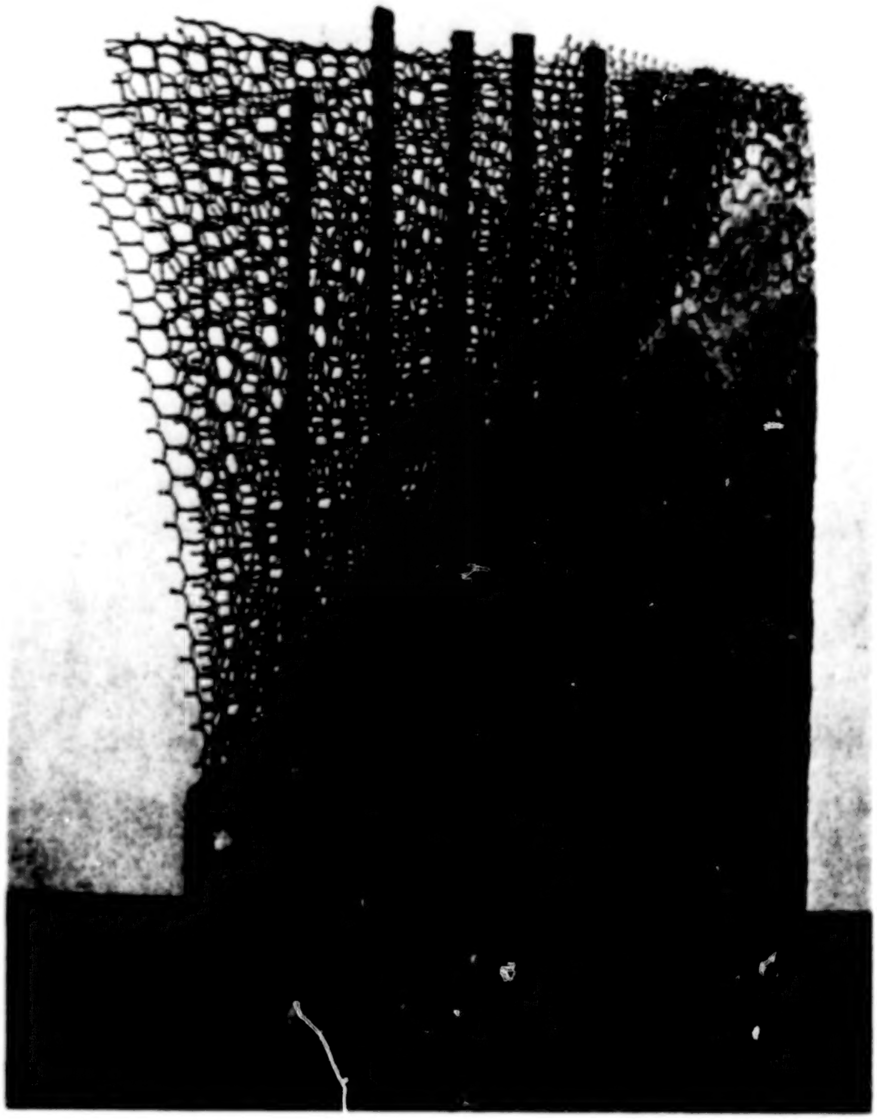


FIGURE 16 A typical ferrocement section. (R. B. Williamson, University of California, Berkeley)

internal trucking costs). With less wire surface exposed to air, this method may, under corrosive tropical conditions, reduce deterioration during storage. A simple handloom could be adapted for weaving the wire into mesh.

For most purposes, the mesh need not be welded. Nongalvanized wire is excellent, though it will rust if stored in the open too long. Standard galvanized meshes (galvanized after weaving) are adequate.

CEMENT, SAND, AND WATER

The quality of cement used is not too critical. Ordinary Type 1 or 2 portland cement is adequate; grades for more specific purposes are unnecessary even for boatbuilding. Grading the sand is seldom important, except to

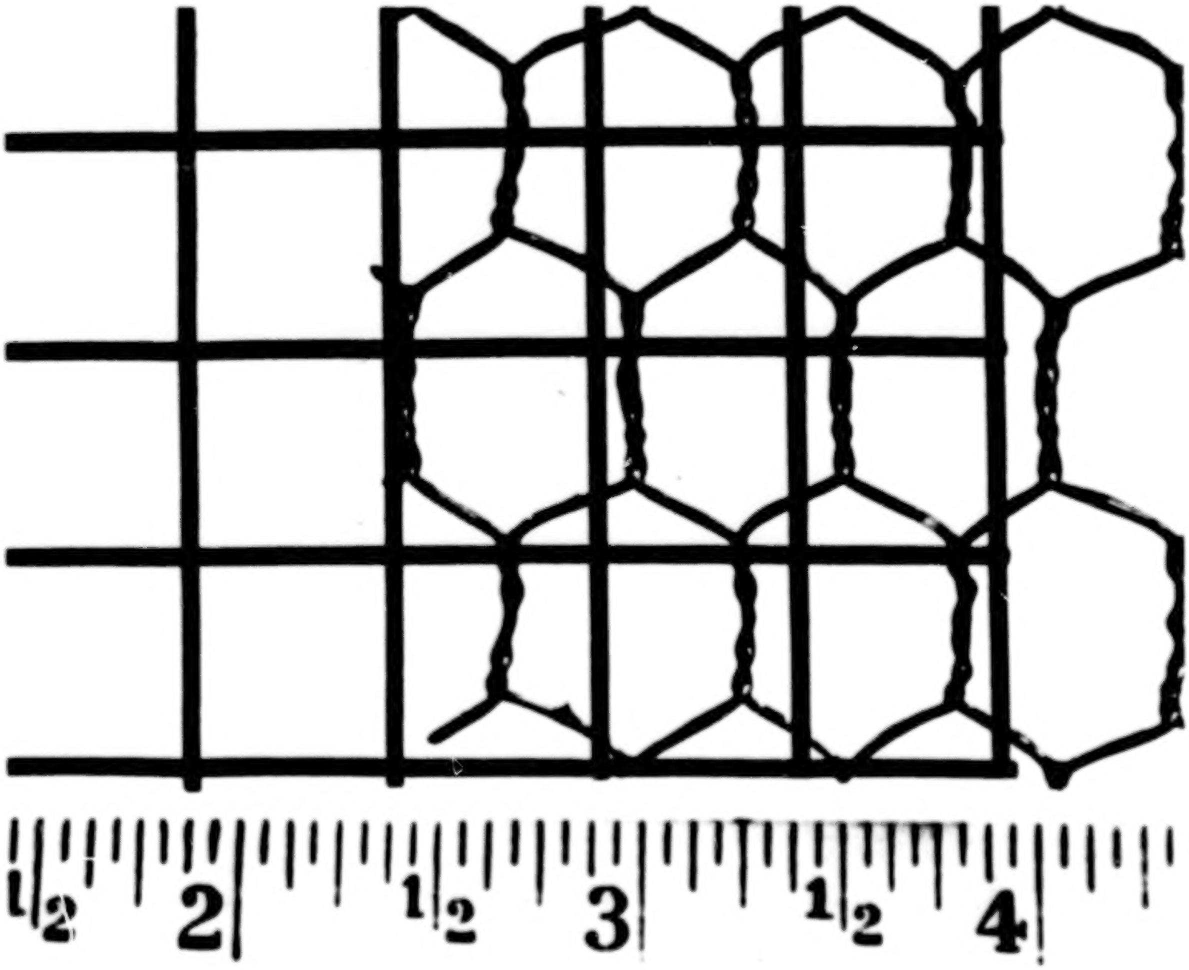


FIGURE 17 Types of reinforcing mesh commonly used for ferrocement. (R. B. Williamson, University of California, Berkeley)

improve mortar workability. Current experience indicates that volcanic sands and beach sands are adequate, but sand should not have an excess of fine particles. Experiments need to be made in using coral sand as a substitute for regular sand, which is not readily available in some areas. Organic debris and silt that will not bond to the mortar reduce the strength of the ferrocement and should be washed out. Water containing these impurities should also be filtered and purified; otherwise, water quality is not critical in general practice.

CONSTRUCTION

The three major problem areas in ferrocement construction are mortar mixing, mortar application, and curing. The mortar must be dense and compact. A trained supervisor can teach the mixer operator to judge mortar quality from the way it tumbles or rolls off the mixer blades. A general mix

FIGURE 18 Mixing the mortar. (Noel D. Vietmeyer, National Academy of Sciences)

is 1 part cement, 2 parts sand. Water is added to give the required pastelike consistency (roughly 0.4 parts water by weight). A horizontal, paddle-bladed mixer is recommended for highest-quality mixing; it is critical for deep-water boats. For land uses, experience shows that hand-mixing is also satisfactory. Determining the cement-to-water ratio can be done with adequate accuracy by observing the mortar's consistency. Sand normally does not have a fixed moisture content; even in the same sandpile, the bottom layers tend to be more wet than the upper ones.

Fingers and trowels are used for mortar placement in the mesh structure. Mortar guns are not recommended because the heavier parts of the mortar (i.e., sand) tend to separate out. A certain amount of vibration helps to produce complete mortar penetration of the mesh and assure good compaction. An orbital sander (a simple power tool used widely in woodworking) with a metal plate substituted for the sandpaper pad has been found to

provide the correct amount of vibration; the vibration is localized, so already-placed mortar is not shaken out of the mesh. It is also possible to create enough vibration by using a piece of wood with a handle attached, though this not recommended for building deep-water boats.

Finally, certain conditions for adequately curing the mortar are essential. The warmth and humidity of most tropical regions is conducive to the rapid curing of ferrocement, but ferrocement must not be exposed to excessive drying action of the elements. It should be kept moist at least 7 days and protected from the sun and wind, both of which reduce the concrete's strength by drying out surface moisture.

NOTE FOR ARCHITECTS AND ENGINEERS

As in the case of conventional reinforced concrete, the mechanical properties of ferrocement depend to a large extent on the properties of the cementitious matrix and the reinforcing steel. The apparent tensile properties of ferrocement represent a significant departure from that of ordinary reinforced concrete in that the dispersed reinforcement changes the observed

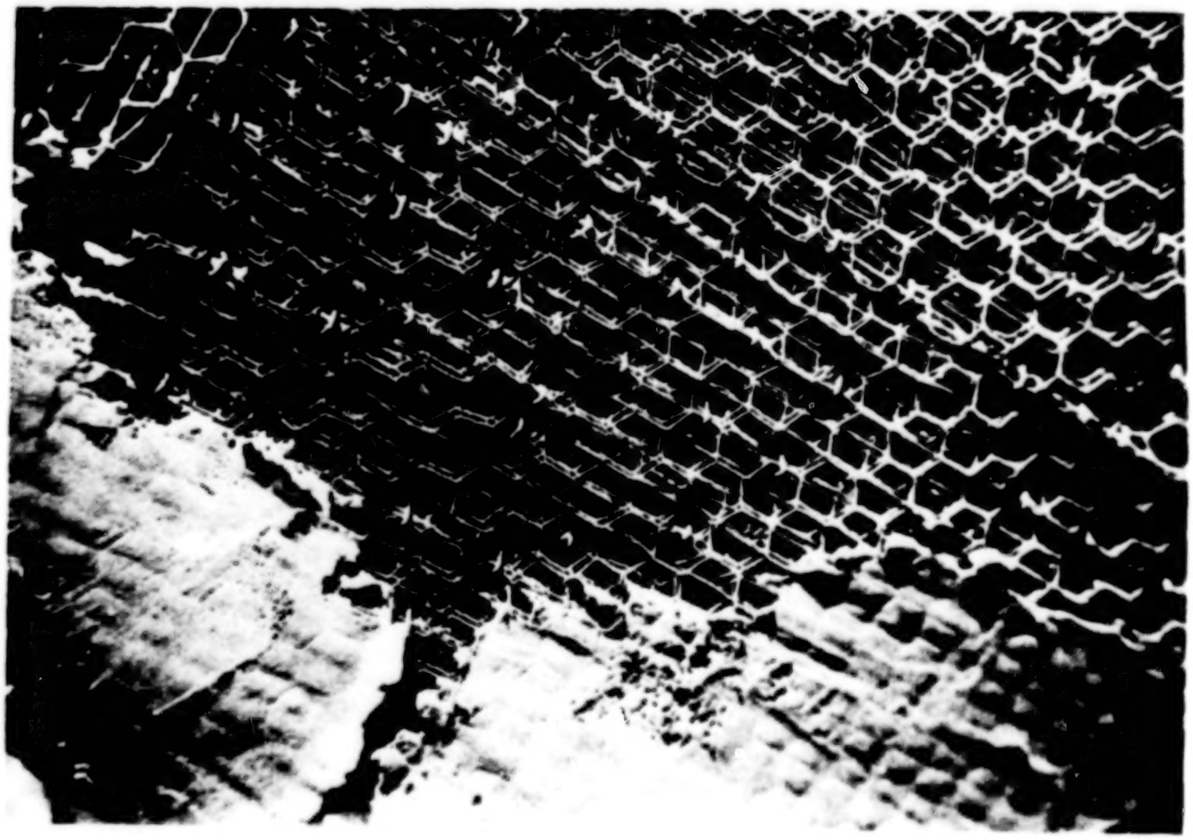


FIGURE 19 Fresh mortar applied to multiple layers of chicken-wire mesh on a 45-foot boat–showing the low-moisture mix that produces a watertight structure. (Noel D. Vietmeyer)

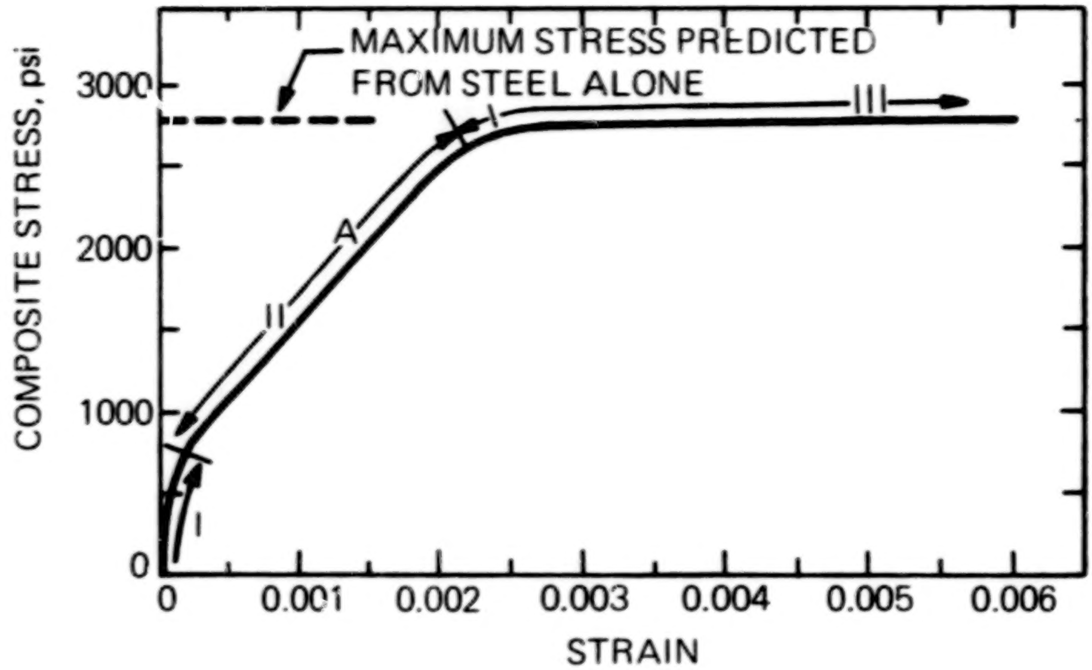


FIGURE 20 The three stages of typical stress-strain curve for ferrocement. (Walkus, I. R. [Lodz Technical Univ., Poland], and T. G. Kowalski [Hong Kong Univ.], "Ferro-Cement: A Survey." *Concrete* [London]. Vol. 5, No. 1. Feb. 1971)

cracking pattern. At a microscopic level the cementitious matrix is responding in the same way, but at the macroscopic level the first tension cracks generally appear at stress levels higher than for unreinforced mortar.

The setting of portland cement is the basic reaction in the fabrication of ferrocement. This setting process is identical to that of hardening conventional concrete, but special precautions must be taken if high levels of performance are expected. To produce an impermeable thin shell, for example, the mortar must have a low water-to-cement ratio. A proper moist-cure period is also imperative. Both of these ideals are readily appreciated by engineers and architects, but it may take special attention to achieve them in the field.

Figure 20 shows a typical stress-strain curve for ferrocement. In stage I the material behaves in a linearly elastic manner with both the reinforcement and the matrix deforming elastically. Then, as the load increases, the cementitious matrix cracks, and stage II begins where there is a change of slope in the stress-strain curve. It has been shown that the stress at the first crack can be increased by increasing the surface area of the steel exposed to the cement, by decreasing the diameter of the wire, by increasing the volume of reinforcement. These cracks are very fine and can be seen only by special lighting effects or microscopic investigation. For most purposes, the materials are unchanged by loading into this region, which constitutes ferrocement's practical working limit. Finally, stage III corresponds to the latter stages of deformation where the full load is being carried by the reinforcement. The

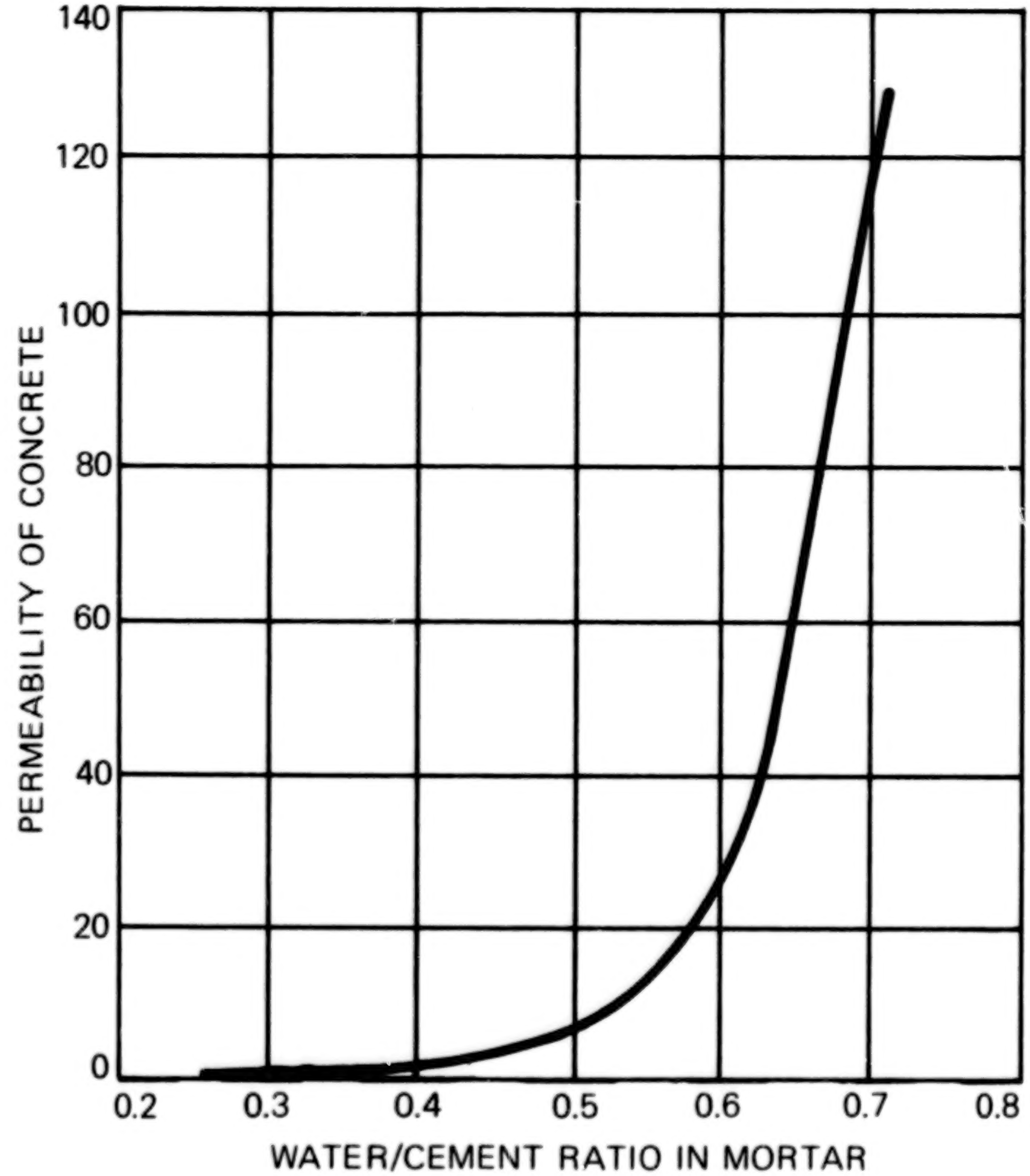


FIGURE 21 Relationship between permeability and water-to-cement ratio (weight basis) for mature portland cement pastes (cement hydrated 93%). (R.B. Williamson, University of California, Berkeley)

stress limit of stage III can be predicted by considering the maximum load-carrying capacity of the steel reinforcement alone.

To put the mechanical properties into perspective, it is important to keep in mind that there is a transition from the characteristic behavior of ferrocement to that of conventional reinforced concrete and that much of the use of ferrocement in developing countries probably will fall on or near this transition. One of the important objectives in the future development of ferrocement will be a rational design system to cover the response of the structure to normal conditions, as well as the ultimate behavior of the structure. Engineering research is needed in this area.

The influence of the water-cement ratio on porosity has a great effect on the shrinkage, strength, and permeability of the final product. However, the practical upper limit of water-cement ratio for ferrocement depends on the acceptable value of permeability, since it is clear from Figure 21 that ferrocement made from mortar with a water-cement ratio of more than about 0.6 has a very high permeability.

The primary requirement for making waterproof mortar is tight control of the water/cement ratio, with the workability obtained by the gradation and quantity of sand as well as by the optional use of certain admixtures. This is also the prescription for making high-quality conventional concrete. Ferrocement is not as forgiving of careless practices as conventional concrete, and in the field it demands new degrees of control, compared to the simplicity of poured-concrete techniques.

Applying the mortar and ensuring that it penetrates the layers of mesh without leaving air pockets—a problem in ferrocement construction—is a particularly severe problem in boatbuilding.

Because ferrocement reinforcing has a somewhat different purpose from that of conventional reinforced concrete, these two considerations apply:

1. Adequate cover to protect the steel from corrosion is necessary because in almost every application of ferrocement, the durability and resistance to environmental effects depend on the thin mortar cover over the steel mesh and its ability to protect the easily corroded steel mesh.
2. It is desirable to have the mesh as near the surfaces as possible.

In a thin shell of ferrocement these considerations conflict; therefore, it is necessary to use a mesh of high-specific surface area (small-diameter wires) in the outer layers, and to use the lowest possible water-cement ratio to achieve the lowest permeability and greatest protection from reinforcement corrosion.

NOTE. Seawater places extra demands on ferrocement. Boats for marine use must be plastered with a cement resistant to sulfate attack. The surface should also be coated with paint or another sealant to further decrease saltwater penetration.

APPENDIX *A*

Ferrocement Boatbuilding in a Chinese Commune

The eight photographs herein of ferrocement boatbuilding in a commune in the People's Republic of China are the first such to be published in the West. They show a large boatbuilding program in which simple ferrocement craft are produced with unsophisticated techniques in a rural area of a developing country. The photographs were taken by Anne Keatley, of the National Academy of Sciences, who visited the People's Republic in June, 1971.

The following text includes a report by Robert Keatley, a journalist who observed the site in 1971, and an analysis by the NAS panel of a total of 26 photographs.

First, the journalist's account:

A drive from Shanghai through the nearby countryside quickly shows a visitor why small boat construction is an important activity there. The rich land is flat, nearly marshy; dry surface is so scarce that peasants use asphalt roads for drying their grain harvests–it may slow traffic, but the land itself remains too wet.

But such roads are scarce in coastal China, a land criss-crossed by rivers and canals. Thus, historically, the sampan has filled the transportation role occupied in northern China by the horse cart.

Horse Bridge People's Commune is probably more advanced economically than its neighbors; it is often singled out as a place to take foreign visitors. Yet it remains a poor place. Its 36,000 people farm an area of only 8,000 acres, including a maze of canals and rivers, and the space alloted for buildings, and the 7 percent total given over to private plots. Its vehicle assets comprise little more than a few tractors and eight rubber-tired carts. The boat retains its importance as a means of moving goods within the commune, and outside it.

Horse Bridge Commune has more than 50 workers assigned to ferrocement boat construction, and they average more than one completion daily. The factory is a sideline for the commune; it produces boats according to a plan worked out by the county and

sells its output to the county, which resells them to users elsewhere in the region.

The most common sizes are 12-meter boats with 6-ton cargo capacity, and 15-meter boats with 10-ton capacity. Construction began in 1964. Recently, the factory has produced a 60-ton capacity boat and plans to try installing a diesel engine. The smaller ones are towed or poled along the still canals. Open cargo holds for carrying night soil are standard features of most, if not all, boats.

The commune sells its 6-ton boats for 750 yuan (US $330) and charges 1,700 yuan (US $740) for the 10-ton size. It claims to realize a 7 percent profit for the commune.

Workers cite "ten superiorities" over wooden sampans, including longer life and cheaper maintenance. They claim a wooden sampan will last 20–30 years with good care; they don't know yet how long a concrete boat will last. The amount of material needed is not great; a 6-ton capacity boat needs 800 kilos of concrete and has a total weight of something over 2 tons.

DISCUSSION OF PHOTOGRAPHS

The main design change in converting wooden sampans to ferrocement boats was to make the bilge more rounded. The flat bottom and flat deck are retained, but there seems to be a slightly greater depth of hull to give more cargo space.

The boats are divided into six compartments, but only the three center compartments are used for cargo. The foremost compartment is used as living quarters for the crew of four men, who enter it through a deck hatch. The fifth and sixth compartments are living quarters for the owner and his family and are covered by an awning for shade and shelter. The vessels are propelled by sail and two yulohs (sculling oars). The stern yuloh (starboard side) is used in the conventional manner; the other, positioned over the forward bow (port side), is used also as a sweep.

Ferrocement is used to the fullest extent throughout, but wooden gunwales are used to absorb shock. The boats have a normal rudder attachment—a wooden gudgeon block bolt-fastened to the hull itself. The rudder is of a simple drop type that can be raised or lowered depending on the depth of water.

Before the Second World War, it was reported that such vessels made approximately two trips per month, carrying night soil for fertilizer far into the countryside from the Shanghai area and often returning with vegetables for the local markets. Ferrocement boats are reported to cost only 50 percent as much as the wooden boats they replace and to have added stability and speed, apparently due to the improved hull shape allowed by the conversion from wood to ferrocement.

Although only one hull design is used (for the sake of economy), bulkheads are placed in any of several positions so that compartments can be constructed to hold different cargoes.

CONSTRUCTION

The pictures indicate an extremely interesting boatbuilding operation. In a modern building, the vessels are built upside down over a pit from which the inside of the hull can be plastered. Inside the building are several areas where bulkheads, afterdecks, and foredecks are assembled alone or in combination as subunits of the final boat. These subunits seem to be built in quantity and then used on any of several hulls.

When hull-building starts, high-tensile wires are positioned along what will become the turn of the bilge and the centerlines of the hull; they are held taut with a Spanish windlass and pass over temporary wooden spalls (crosspieces which will hold in place bulkheads and frames of the hull to come). Next, the precast concrete (or welded steel) bulkheads and frames are positioned and attached to the high-tensile wires which hold them upright. The "new moon" shaped frames are spaced approximately 1 meter apart; they are approximately 1 inch thick, 2 inches wide at the ends (deck level), and 6 inches wide at the center (keel level). Once in place, the bulkheads and frames outline the hull and provide shape and support for mesh and mortar that, when added later, form the watertight skin of the hull.

FIGURE A-1 Ferrocement sampans at Horse Bridge Peoples' Commune. Note at extreme left of picture the bow of an upside-down sampan awaiting launching. That sampans are poled indicates that weight does not hinder their traditional performance. (Figures A-1–A-8, Anne Keatley, National Academy of Sciences)

FIGURE A-2 Repairing a damaged ferrocement hull. In the background are wooden counterparts.

Inside the precast-concrete bulkheads are reinforcing rods extending out beyond the concrete. The layers of wire mesh for the skin of the hull are maneuvered down over this protruding reinforcing until they are snug on the bulkhead itself. The bulkhead reinforcing rods are then bent over and laid alongside the hull's reinforcing, and the layers of mesh are firmly fastened to them both.

Three layers of wire mesh are used, and between the innermost layer and the outer two are placed reinforcing rods that run the length of the hull. Extra layers of mesh are placed at potential stress areas, e.g., along the curve of the bilge. The first layers are placed transversely across the hull; later ones are laid along the hull's length.

The photographs show women wiring together the layers of wire mesh. They work from the outside only and have no helper on the inside. Apparently, they use a hooking tool 5 or 6 inches long to maneuver the tie-wire in and out through the layers of mesh. This is an improved technique compared to methods used elsewhere. The wire in the hulls is stretched very tight; some parts are prewelded or precast, but there appears to be no welding during construction.

The wire mesh (square rather than hexagonal chicken wire) is irregular, with

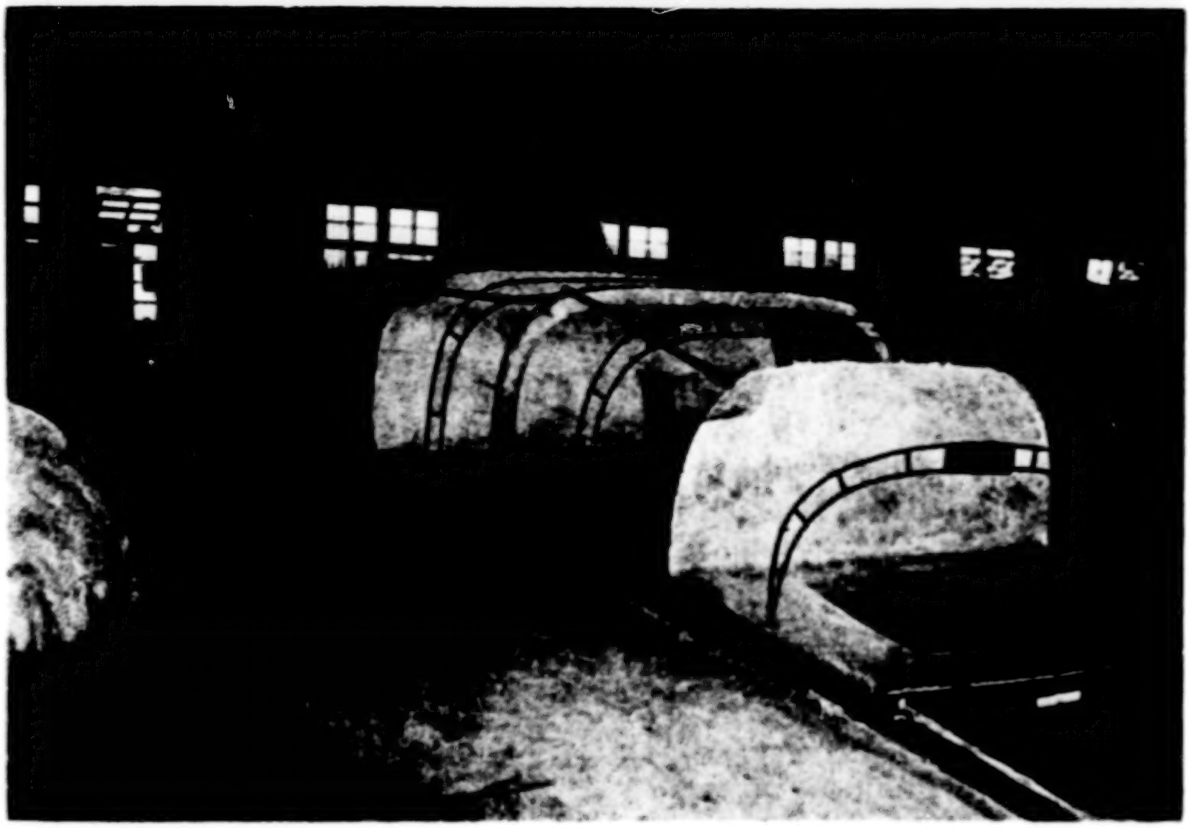


FIGURE A-3 In shaping the sampan (upside down) and the supporting layers of wire mesh, workers use precast ferrocement bulkheads and frames that become part of the final structure, as well as steel frames that are later removed.

FIGURE A-4 Precast ferrocement parts for a new boat are being made in front of a boat that is curing. Note rail tracks used when the completed craft is moved.

FIGURE A-5 Wire mesh is stitched to the underlying frames.

FIGURE A-6 Worker ties together layers of mesh and rods by threading short lengths of wire through and pulling them back with a small hooked tool. Although the construction uses unskilled labor, a supervisor maintains quality control.

FIGURE A-7 While plastered hulls are curing, a team of women builders concentrates on wiring up a new hull. Approximately one boat is produced per working day.

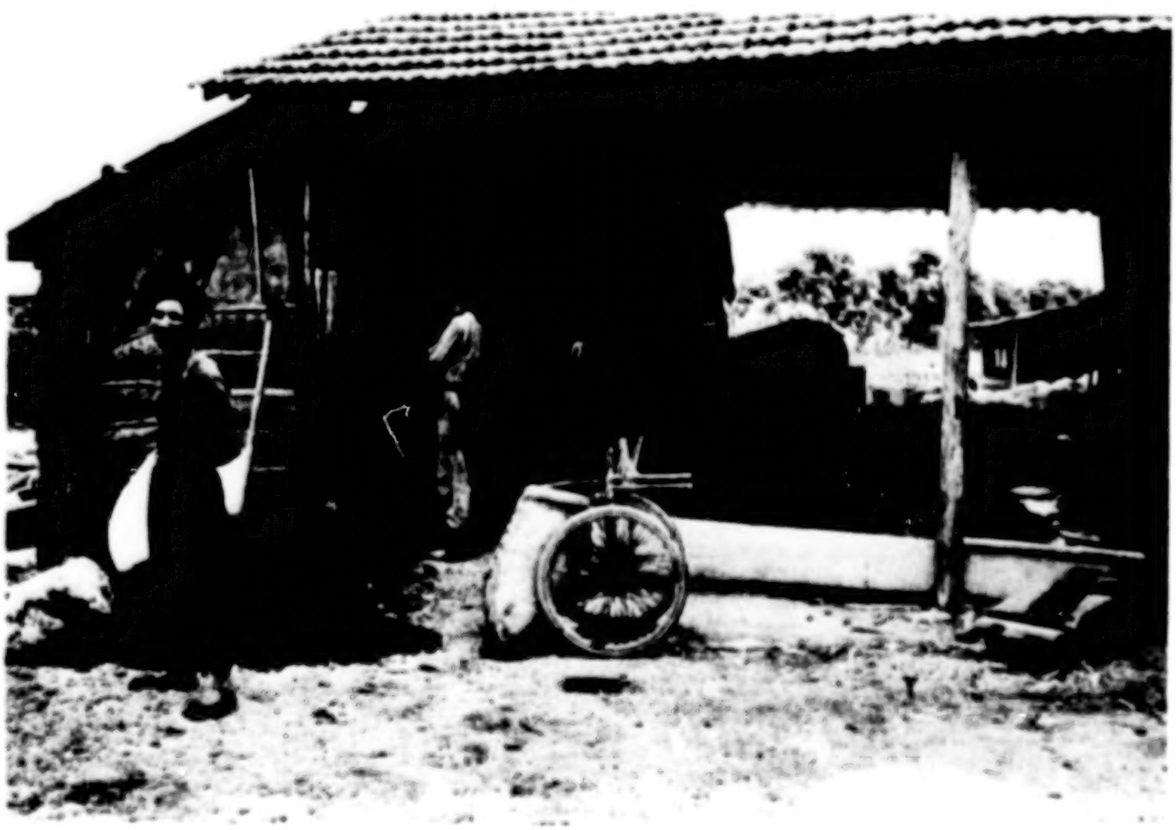


FIGURE A-8 Mortar is mixed under very unsophisticated conditions. A paddle-bladed horizontal mixer is used.

varying distances between the strands. Close inspection of the photographs indicates that the mesh itself is probably woven from single-strand wire in the commune (or at a nearby location). The ends of the mesh appear to have been looped and are not square, further suggesting that they are handwoven.

The longitudinal reinforcing rods appear to be about 1/4 inch in diameter, are spaced approximately 3 inches apart, and are securely fastened to the mesh. Apparently, there is no other longitudinal stiffening.

ORGANIZATION OF THE BUILDING SITE

An analysis of 26 photographs suggests that 9 or probably 10 boats are being built and cured simultaneously. If the ferrocement is allowed to cure for 14 days, 2 boats could be built per day, yielding 18 to 20 boats per month. It is possible to shorten the curing time on land to 5 or 6 days if the remaining cure is done under water. Though the photographs show no positive evidence, it appears quite probable that this is done.

No pictures show the actual plastering operation; however, one freshly plastered hull and two being cured are visible. Curing is done by draping wetted fiber mats (hessian or burlap) over the hull. A sprinkler system may be used to cure the interior surfaces.

The boats are launched upside down, either to be rolled over in the water or to right themselves by their buoyancy, perhaps after final curing by immersion in the water. A crane with a boom about 10 meters long is used to launch the boats. The vessels are moved from the construction shed to the canal bank on a cradle that runs on tracks. The cradle is placed under the boats easily, without need for a crane, because it can be run under the hull and accurately placed by the people working in the pit over which the boats are built. Tracks run from each building bay through a set of railroad points to the canal bank next to the launching crane. The cradle consists of two dollies approximately 1.5 meters long, each having four wheels. The dollies are placed approximately one third of the vessel's length from either end. Once in place, the boat is rolled to the canal bank, apparently by manpower alone.

The mortar-mixing shed is roofed but has open sides and is located adjacent to the main construction building. Water is piped to a standard faucet, and there is a large area for premixing the concrete. A horizontal-type rotary concrete mixer is visible.

CONCLUSIONS

The building and organization are well engineered and produce what is probably a combination (with improvements) of different types of vessels pre-

viously built by individual families. An ever increasing demand to expand the fleet of small boats to cope with population increase may have made it mandatory to devise rapid boatbuilding techniques. Possibly, too, a natural depletion of good boatbuilding timber and the allocation of any available steel to other purposes led to the use of ferrocement.

The lesson to be learned from these photographs is that with proper engineering, mass production in ferrocement is not only feasible, but practical. Standardization of design appears important.

These methods of construction indicate a considerable amount of planning and engineering skill. Precasting sections of ferrocement hulls is a significant advance in construction techniques, one that makes mass production possible. It also suggests new design considerations and new lines for basic research into ferrocement science. In most parts of the world there is considerable controversy over the method to be used to provide support and shape for the layers of wire mesh. Temporary wooden and water-pipe supports are generally used, but both suffer drawbacks, particularly during their removal after the hull is mortared. The Chinese, in contrast, provide support and shape the mesh with precast concrete bulkheads or frames that end up as integral parts of the boats. Furthermore, these precast frames and bulkheads are the key to producing uniformly shaped vessels so that standardized sheets of mesh and fittings can be employed, with resulting economies from building boats of interchangeable parts on a "production line" basis.

Much can be learned, too, from the methods the Chinese use at their urban boatbuilding factories. Photographs of the Wusih ferrocement boat factory published some years ago show 20 hulls under construction inside a modern building.* They also show an even greater refinement in subassembly than in the commune, for all subassembly is done on one side of the building, and the overall construction and plastering on the other. Both steam and air curing operations take place in the same building.

The need for a large number of new hulls forced the Chinese to seek mass-production techniques. Ferrocement has allowed them to do this.

*"Chinese Build Concrete Boats." *Concrete Products.* Dec. 1966. pp. 36–37.

APPENDIX *B*

Ferrocement Food-Storage Silos in Thailand

A family of cheap, airtight bins made of ferrocement, the Thai silos are sized to hold 4–10 tons of grain, other foodstuffs (e.g., peanuts, soybeans), salt, fertilizer, pesticide, cement, or 2,000–5,000 gallons of drinking water. The silos were developed over the past 4 years by a government corporation in Thailand* to fit requirements of the developing world. The designs are versatile; the storage units can be built on extremely adverse sites: where the water table is at the soil surface or in remote areas where even vehicular access is impossible. These bins require no maintenance, are easily padlocked against thieves, and protect against water, rodents, birds, insects, aerobic micro-organisms, weather, and serious loss of seed germinability.

These properties are made possible by using the material and methods of ferrocement boatbuilding. This construction produces a high-quality product that can be built by local labor with minimal supervision.

The materials needed are cheap and readily available in developing countries: standard grades of cement, a wide range of wire meshes (e.g., chicken netting), and sand. (See Table B-1.)

As previously noted, the ferrocement bins are watertight and airtight. Respiration of grain, or similar product, quickly removes oxygen from the atmosphere in the bin, so that any insect (adults, larvae, pupae, or eggs) or

*Applied Scientific Research Corporation of Thailand, Bangkhen, Bangkok-9, Thailand.

TABLE B-1. Cost Record for First Experimental Thailo, Thailand, 1969

Inputs	Quantity	Thai Cost (in U.S. $)
Labor		
Skilled	63 man-hours[a]	$ 24
Unskilled	135 man-hours[a]	20
	Total Labor Costs	$ 44
Materials		
Cement	1,000 kg	25
Sand	1,725 kg	3
Aggregate	965 kg	3.5
Mortar plasticizer[b]	2 kg	2
Sealant for the base[b]	5 kg	2
Paint	3/4 kg	7.5
Steel		
Chicken wire	2 rolls	18.5
No. 2 rod	80 m	2.5
Water pipe[b]	32 m	13
	Total Materials Costs	77
	TOTAL	$121

[a] Labor figures refer to an initial experiment and can be drastically decreased in practice. Construction of several Thailos at the same time also reduces labor costs because time spent waiting for sections to cure can be used productively on adjacent bins.

[b] Used to date because of availability in Thailand but may not be necessary for adequate perfo..nance of completed Thailo.

SOURCE: R. B. L. Smith, *et al.*, *Thai J. Agr. Sci.* 4 (July 1971): 143–155.

aerobic microorganisms present cannot survive to damage the stored product. Thus, no fumigation is needed.

Thailos are easy to use. They are filled through a hatch in the top and emptied through another at ground level. The sides are sloped for firm support of a ladder (Figure 11), and the fairly low height (7 feet, or a 5-step ladder) of the entrance hatch simplifies manual filling from sacks or buckets.

As with any type of silo, it is important to dry the grain before loading; otherwise molding may occur. Tests to investigate the feasibility of on-site drying, using a fan and small engine (designed by the Tropical Products Institute*) to force warm air through the product while it is in the Thailo have been conducted successfully in Thailand.

*56/62 Gray's Inn Road, London WC1, England.

TECHNICAL DETAILS OF THAILO CONSTRUCTION
(See Figures B-1 – B-3.)

The base of the Thailo is saucer shaped and, where necessary, is built on an earth pile to raise it above the water table. This gives a strong, easily constructed structure that can resist foundation failure. It consists of two layers of 5-cm-thick concrete (1 cement: 1½ sand: 2 aggregate) with mesh reinforcement and an asphalt seal between as added protection at building sites subject to flooding. The base may be easily modified to suite different ground conditions.

The walls slope inward to a central entrance hatch at the top. This truncated cone shape gives a very rigid structure, both during and after construction, and it eliminates the need for a roof structure. The walls are reinforced with 2-m-long poles (water pipe or bamboo), reinforcing rods, and one layer of wire mesh on internal and external faces. The mortar is hand-mixed and is applied as a thick paste using trowels and fingers. No formwork is required to support the mortar. The wall mortar consists of 1 part of standard cement, 1.75 parts sand with the optional addition of a plasticizer to improve workability. Water/cement ratio is approximately 0.3, and with only enough water to hydrate the cement, no voids due to excess moisture are left in the ferrocement, which becomes impermeable.

The top may be cast on site or precast and erected before cementing the walls. It consists essentially of a ferrocement lid with circles of rubber to make airtight seals. An

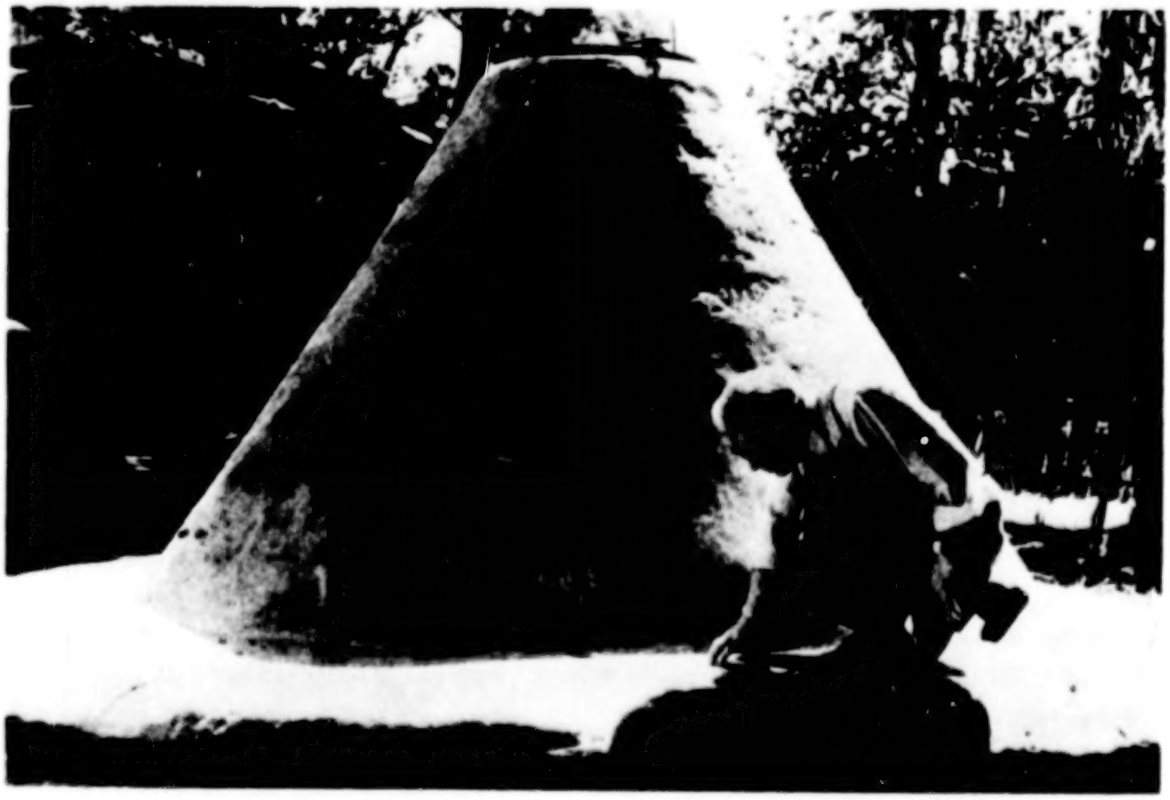


FIGURE B-1 Severe floods on a village farm in Thailand floated this silo off its earth foundation, but it was reset, still dry inside and undamaged, when the floods subsided. This ability to resist vagaries of foundation conditions is an important characteristic. (R.B.L. Smith, University of Nairobi, Kenya)

inner lid of aluminum (trashcan lid) with a polystrene lining to insulate against heat and to prevent moisture condensation can be also used.

Controlling the water content of the mix and curing for several days under moistened sacking to avoid direct exposure to the drying effects of sunlight and wind are paramount construction considerations. On completion, the bin may be tested by filling it with water for 1 week. This is an excellent quality-control test because water is considerably more heavy than products likely to be stored and any cracks or weak sections, caused by poor workmanship, can be readily seen as leaks.

FIGURE B-2 Ferrocement construction is straightforward, but labor-intensive: Construction of the walls begins after the base is complete. Mesh from base is integrated into the walls, which are strengthened with waterpipes or bamboo struts. Then horizontal hoops of reinforcing rod are wired to the struts. (Applied Scientific Research Corporation of Thailand)

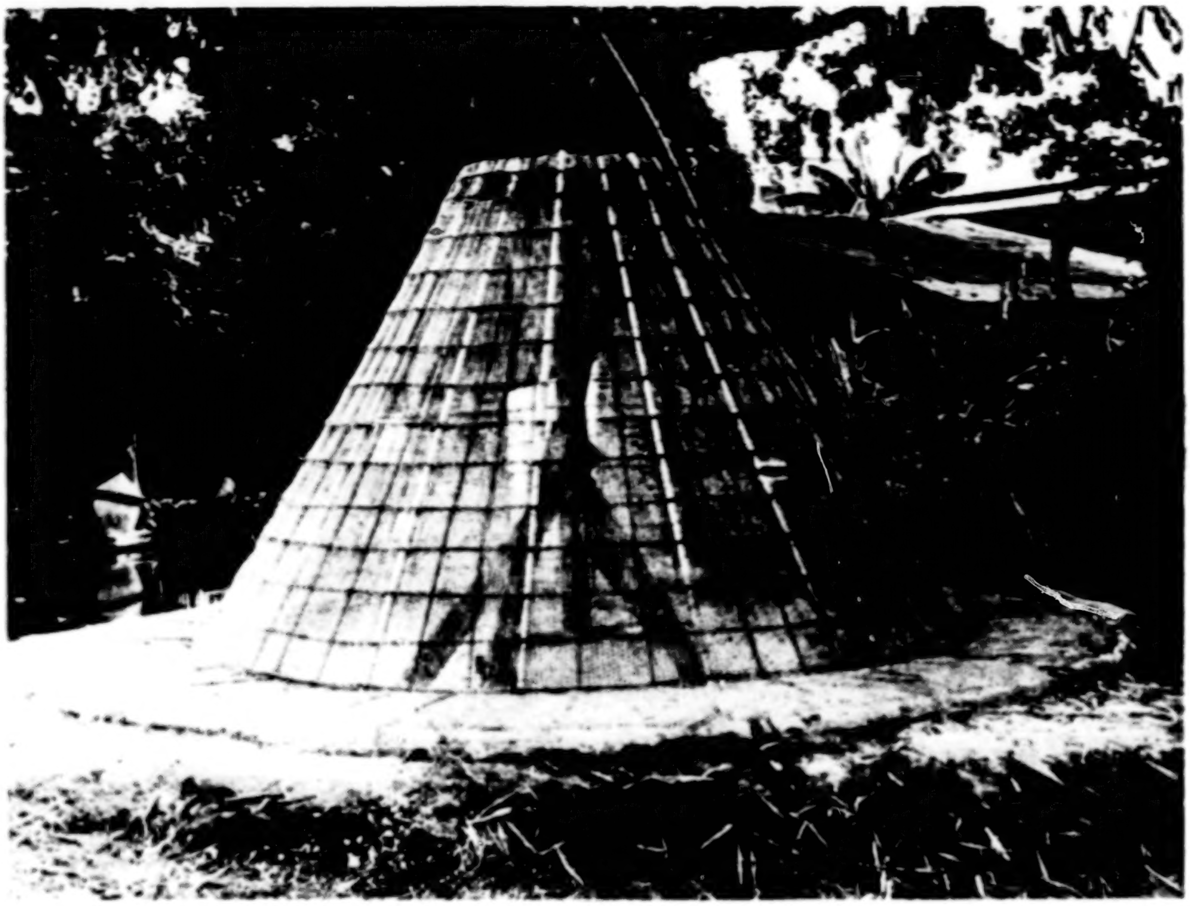


FIGURE B-3 The frame is completed with one layer of wire mesh on the outside surface and one on the inside. Mesh, reinforcing rods, and struts are fastened together with short lengths of wire threaded through the wall and back and twist-tied with pliers. (Applied Scientific Research Corporation of Thailand)

APPENDIX *C*

*Ferrocement-Lined Underground Grain Silos in Ethiopia**

In Harar Province, Ethiopia, underground pits are the traditional method of grain storage. It is estimated that 62 percent of the farmers use pit storage exclusively and a further 8 percent use pits in combination with other storage methods.** The basic shape of pit stores resembles that of a laboratory conical flask. The mouth of the pit is closed by strips of wood sealed with a mixture of mud and dung. The pits, if fairly well sealed and covered with a good depth of hard-packed soil, should provide a reasonably airtight storage chamber. In such a chamber any insects present in the stored grain should be killed as the oxygen is used up.† However, unless the pit and grain are both dry, some mold growth is inevitable. In practice, few traditional pits are sufficiently airtight to eliminate insects, and mold damage is often considerable.

When the traditional pit is lined with ferrocement and provided with an improved airtight lid, a truly hermetic and waterproof storage chamber can be achieved.

Traditional pits in Harar Province hold from ½ to 20 tons of grain, but there are records of pits holding 50 to 70 tons. In theory, even the largest could be ferrocement lined, but to date the largest lined pit has a 7-ton capacity. This pit was approximately 3 meters deep and 4 meters at maximum width. Most lined pits hold ½–2 tons. A ½-ton pit is approximately 1 meter

*Report prepared by R. A. Boxall, November, 1972. The work described was part of a grain-storage project in Ethiopia sponsored by the United Kingdom Committee of the Freedom from Hunger Campaign and Christian Aid, 1971–1972.

**Anon. (1970). *Report on a Survey of Hararge Province*. Imperial Ethiopian Government, Central Statistical Office, Addis Ababa.

†Hall, D. W. and M. E. Hyde (1954), "The Modern Method of Hermetic Storage." *Trop. Agriculture*, Trin. Vol. 31, No. 2, pp. 149–160.

deep by 1 meter at the widest point; a 2-ton pit is correspondingly 1.75 meters by 2 meters.

Pit stores are built in all the major soil types of the province. Ferrocement linings have been shown to be satisfactory in even the wettest soil.

The ferrocement lining can be produced by any local laborers who are familiar with the use of cement in house building, but even local unskilled laborers can soon learn to do the work satisfactorily. After a 2–3 hour training period, unskilled laborers were able, without close supervision, to help other untrained workers with the techniques.

Although the materials needed are relatively cheap, they are sometimes beyond the reach of the small farmer. For these cases some assistance is likely to be forthcoming when the farmers' cooperatives, now in the early stages of development, become established. A factory in Dire Dawa, one of the two largest towns in the province, makes a standard grade of cement which is distributed throughout the province to even the smallest villages on a main highway or all-weather road. Wire mesh, in various grades, is available in all the major towns and in most villages served by an all-weather road. In most areas sand is available from dry riverbeds, but in some parts of the province graded and washed sand can be obtained.

Extension agents of the Imperial Ethiopian Government, Ministry of Agriculture, have been closely involved with the development of the improved pits and have received training in the use of ferrocement linings. Through this agency the general ideas of pit improvement are being disseminated to the local farming communities.

TABLE C-1. Costs of 1-Ton Ferrocement-Lined Storage Pit, 1972 (in U.S. $)[a]

Using a bitumen lining as waterproofing barrier	
Labor (skilled)	$ 3.50
Labor (unskilled farmer assisting skilled laborer)	nil
Materials	
Cement	5.20
Sand	nil
Aggregate	nil
Bitumen	1.00
Chicken wire	2.20
Miscellaneous–transport, hiring tools, etc.	2.10
	$14.00
Using bitumen emulsion ("Flintkote")	
Extra cost $6.50, therefore total	$20.50

[a]Based on average for all of Harar Province, Ethiopia. In remote areas, the price of materials is likely to be higher; in areas close to large towns, considerably lower.

TECHNICAL DETAILS OF FERROCEMENT PIT CONSTRUCTION (See Figures C-1 – C-3.)

Before a pit is lined, a thorough cleaning operation is carried out: all rubbish is removed, and, when necessary, the walls are smoothed by scraping off loose soil. Evidence of termites is sought, and if found, the walls of the pit may be treated with an appropriate termiticide. A layer of hardcore is laid on the floor of the pit to a depth of about 10 cm, and a layer of concrete is laid on top. A layer of mortar 2.5–3 cm is applied by hand and trowel to the walls. The mortar consists of 1 part cement to 3 parts sand with as little water as possible. A chicken-wire mesh reinforcement is tacked onto the surface while it is still moist, and a second layer of mortar is applied on top. The lining is moist-cured for 5 to 7 days, after which a waterproofing coat is applied. The surface is prepared by brushing off loose material with a wire brush, and a priming coat of bitumen emulsion is diluted 1 volume of emulsion to 1 volume of water and applied with a stiff brush. The emulsion is scrubbed well into the cement layer. After the priming coat is dry, a bonding coat of neat emulsion is applied and allowed to dry. Finally, a cement/emulsion mixture, using 1 volume of water to 1 volume cement to 10 volumes of emulsion is prepared and brushed over the whole surface of the lining.

Because this waterproofing method using bitumen emulsion is a relatively expensive and sophisticated treatment, a single layer of bitumen has been tested. This layer, applied

FIGURE C-1 A final layer of mortar is added to an improved storage pit. (Figures C-1–C-3, Robin A. Boxall, Freedom from Hunger Campaign, Ethiopia)

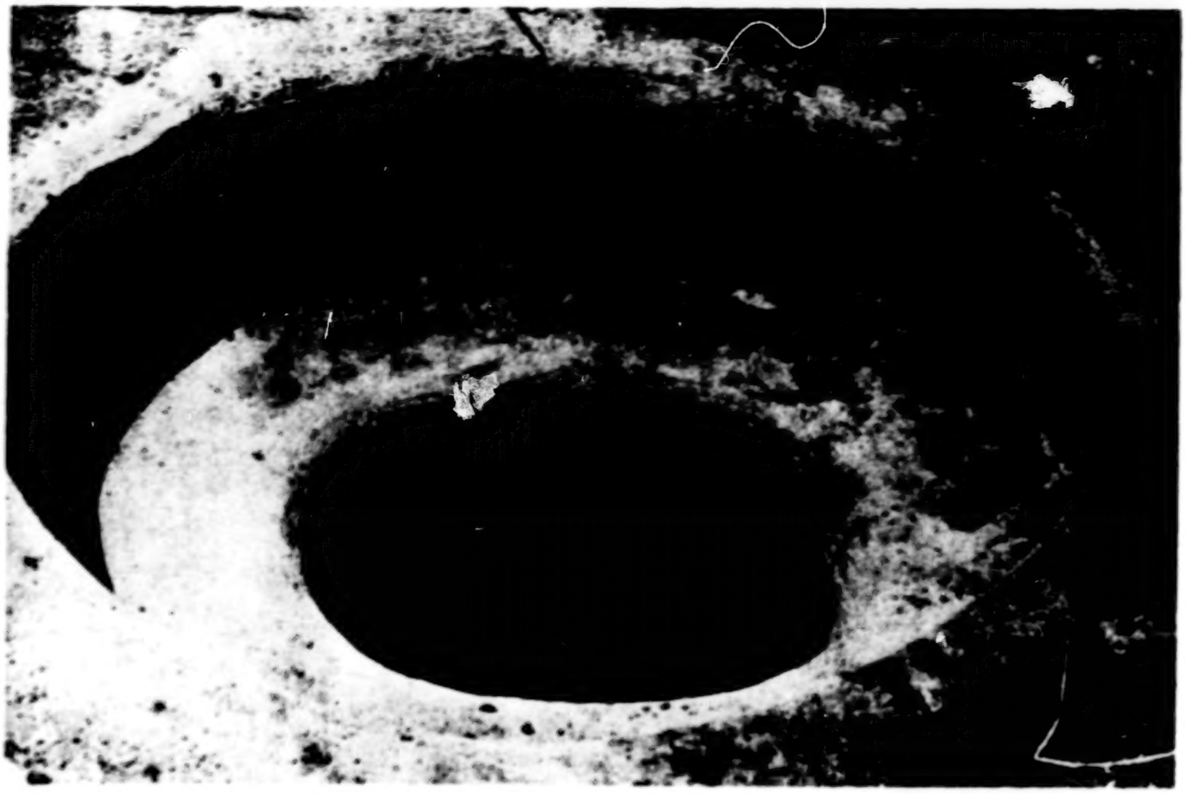


FIGURE C-2 Mouth of finished ferrocement-lined underground silo in Ethiopia.

between the two cement layers, has been found to be perfectly satisfactory. However, bitumen is available only in large drums and is rather difficult to apply to the sloping walls of a pit. No really easy way of applying it has yet been found.

The design of the mouth of the pit has been modified to incorporate a sloping lip, which will carry away any water that might penetrate the soil. Drain pipes can easily be included to carry the water even farther from the pit (Figure C-3).

The traditional wood-strip lid can be used with the lined pit; however, when a metal or concrete lid is used with a sealant such as bitumen, a truly airtight store can be obtained. Condensation on the inner surface of metal lids sometimes occurs, but can be avoided by use of a piece of old sacking as an inner liner.

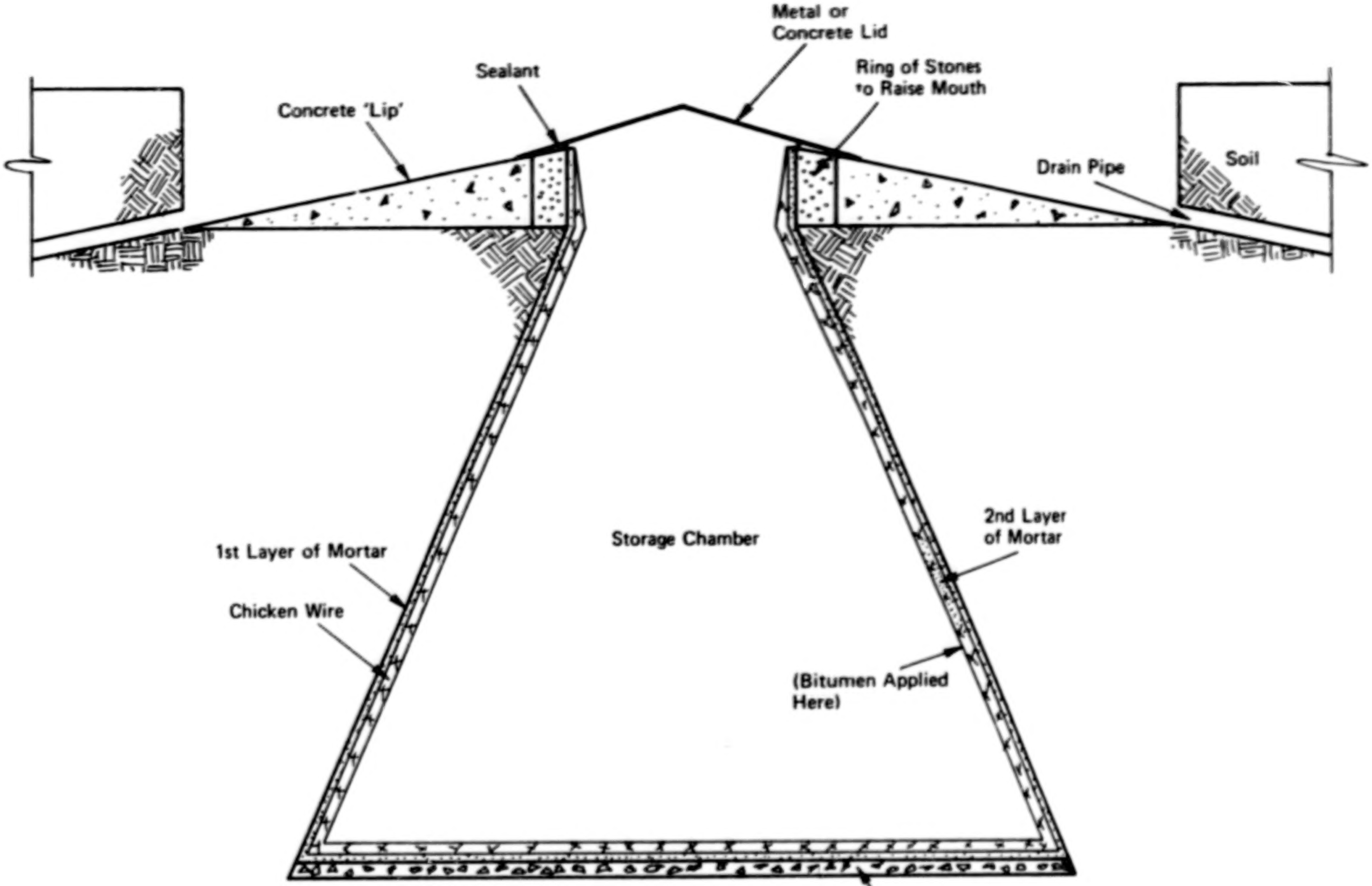


FIGURE C-3 Cross-section of ferrocement underground storage pit.

APPENDIX *D*

*New Zealand Ferrocement Tanks and Utility Buildings**

Perhaps the greatest development in farm water storage in New Zealand has been the introduction of ferrocement tanks,** which retain most of the advantages of earlier tanks with few of their limitations. The cost of smaller sizes is comparable to that of other tanks, but the storage cost per gallon drops off rapidly when larger sizes are used. Paralleling this consideration is the continuing economy offered by the indefinite life of the ferrocement tank.

In most parts of the country, ferrocement tanks are available as stock items in sizes ranging from 200 to 5,000 gallons. Thus, the factory can deliver a tank ready for pipe connections directly to the prepared base. If required, tanks larger than 5,000 gallons can be constructed on site by the same system used at the factory.

The widespread availability of ferrocement tanks and the versatility of the material provide the farmer with economic water-storage facilities involving only minimum site work. Permanent materials are used throughout, and, since all work can be controlled in the factory, most manufacturers confidently offer a 25-year guarantee on their products.

*Based on information supplied by the New Zealand Portland Cement Association, Wellington.

**It should be noted that although these tanks are said to be made of "ferrocement," the steel mesh used is rather large in opening size compared with most ferrocement construction. The openings are about 2 inches, and only one layer is used. It appears likely that reducing the mesh openings below this might well improve the crack resistance of these tanks and allow thinner walled construction. However, their success and versatility illustrate that good performance can be expected from ferrocement even when requirements for reinforcement quantities and sizes are substantially relaxed from the stringent specifications required for deep-water uses.

Factory-produced tanks are designed for convenient handling with simple equipment. Small tanks are loaded on the truck, and unloaded by a truck-mounted hoist. Usually, tanks over 1,000 gallons (4,500 litres) are winched onto the truck.

Site preparation is a simple matter, usually calling for no more than removal of vegetation and trimming the soil roughly level. If the tank is to be placed on rock, or if it is desirable to provide a concrete base, a layer of sand must be spread under the tank. This prevents point contact, which would generate high local stresses and probably result in cracking.

The tank is then ready for pipe connections. Generally, standard pipe fittings are built in during manufacture, but special items can be provided by arrangement. If necessary, additional items may be installed on site by chipping a hole and plastering the fitting in place.

Perhaps the most obvious adaptation from water-storage tanks is to tanks of other forms, such as sheep or cattle troughs and septic tanks. Septic tanks

FIGURE D-1 A 5,000-gallon ferrocement household water tank is fed from rain collected from the house roof. A small header tank built into the top provides the household with a constant water pressure. (Figures D-1–D-3, New Zealand Portland Cement Association)

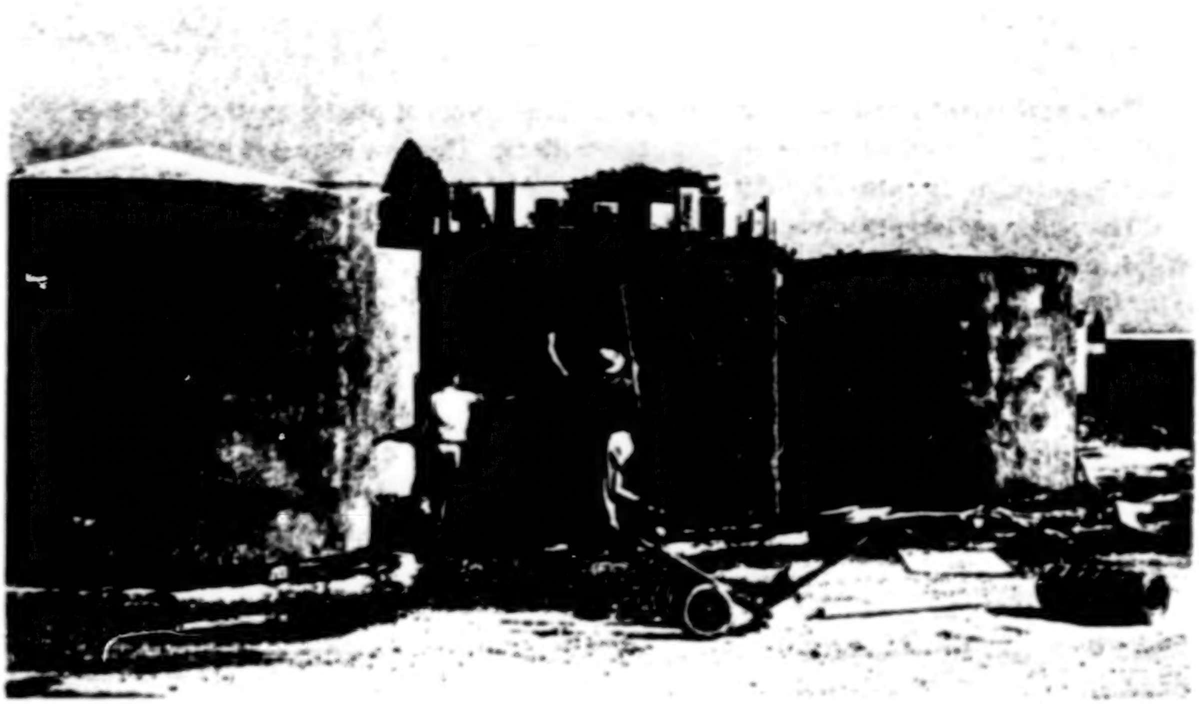


FIGURE D-2 Ferrocement 5,000-gallon water tanks under construction in New Zealand.

are constructed with earthenware fittings and are supplied ready for installation. They are manufactured in various forms, with the actual details determined somewhat by requirements of local governing bodies. (See Figure 5.)

Impermeability is an important characteristic of ferrocement in its use for water retention. Since impermeability promotes hygiene, this material is frequently used where hygiene is of prime importance. Most tank producers have a range of killing sheds, dairies, and freezing chambers—all constructed of ferrocement. (See Figure 4.)

By the simple process of placing a window or door frame against the inside former before plastering, the water tank is transformed into a tool shed, site office, pump room, small laboratory, or any similar structure. When required, plumbing and electrical circuits can be embedded in plaster.

Many manufacturers have developed additional features for special circumstances. Instead of using a circular former, as for tanks, the details may be modified slightly so that the office or pump room is square or rectangular. Freezing chambers are constructed of two layers of plaster separated by insulation and vapor barriers. Usually, the freezing equipment is mounted on the roof. Toilet rooms, shower rooms, and laundries are available with all plumbing fixtures in place, so that on site it is necessary to connect only the water supply and drains.

A further advantage of small ferrocement buildings is that relocation at a later date is no more of a problem than the initial delivery from the factory.

TECHNICAL DETAILS

Tanks are constructed by applying two or three layers of plaster against an inside former until the required thickness has been built up. The reinforcing is placed at the stage appropriate to ensure correct location within the wall.

The water pressure in a loaded tank generates hoop stresses in the tank walls. The resulting tension is resisted by a continuous spiral of reinforcing wire, usually No. 8 s.w.g. The spacing of the wire is determined by the diameter and depth of the tank.

Some manufacturers prefer a woven mesh of No. 14 s.w.g. and 1 1/2-in or 2-in mesh; others use a chain netting. In some instances a light welded-steel fabric is incorporated in the lower section of the walls to accommodate additional stresses that develop during handling.

The tank floor, which may range in thickness from 2 1/2 in (6.2 cm) for a small tank to 4 in (10 cm) for the largest, is reinforced with a welded grid of steel. A typical reinforcing is 3/8-in diameter rods welded into a grid at 8-in or 10-in centers (10 mm at 20–25 cm). Loops of light steel project into the wall section, and additional handling loops protrude from the edge of the floor for lifting or dragging the completed tank.

The manufacturing sequence varies from one factory to another. In some cases the floor is cast first; in others it is cast after the walls. Some manufacturers place 1/2 in (12 mm) of plaster against the former, position the steel, and then continue plastering up to a total thickness of 1 in to 1 1/4 (25 to 30 mm). At other plants the reinforcing is

FIGURE D-3 Typical ferrocement tank manufacturer's yard in New Zealand. Over fifty manufacturers build tanks of 200–5,000 gallon capacity. Elliptical septic tanks in the foreground are also manufactured by the ferrocement technique.

placed directly against the inside former, and the main body of plaster is applied. The final layer of plaster is applied from the inside after removing the form.

In all cases a strong concrete coving is provided between the wall and floor to seal and strengthen the joint.

The plaster may be applied either manually or pneumatically.

Most tanks are provided with a flat or conical roof 1 1/2 in to 2 in (38 to 50 mm) thick. The roof may incorporate a separate small header tank to provide constant pressure (Figure D-1). If a roof is not needed, the upper edge of the tank wall is thickened to give added strength.

Finally, the tank is given a cement wash inside and is painted outside with a cement-based paint or other suitable surface coating. A little water is placed in the tank, which is kept in the factory yard for some time before delivery to allow the humid atmosphere to cure the cement fully.

Resumen y Recomendaciones

El ferrocemento es un tipo de hormigón armado sumamente versátil hecho de tela metálica, arena, agua y cemento, que posee características singulares de solidez y durabilidad. Puede ser hecho con un mínimo de mano de obra calificada a partir de materiales fáciles de obtener. Además de ser adecuado para la construcción de botes, tiene muchas otras aplicaciones, tanto potenciales como ya comprobadas, en la agricultura, la industria y en la construcción de viviendas.

El ferrocemento conviene de modo particular a los países en vías de desarrollo por las siguientes razones:

- Sus materias primas básicas son de fácil obtención en la mayoría de los países.
- Puede dársele casi cualquier forma de acuerdo con las necesidades del usuario; los diseños tradicionales pueden reproducirse y a menudo mejorarse. Elaborado en la debida forma, es más durable que la mayor parte de las maderas y mucho más barato que el acero importado, y puede utilizarse en sustitución de estos materiales con usos muy diversos.
- Las destrezas implícitas en la construcción a base de ferrocemento se adquieren con rapidez, e incluyen muchas que son tradicionales en los países en vías de desarrollo. La construcción con ferrocemento no requiere ni instalaciones pesadas ni maquinaria; emplea una alta proporción de mano de obra, se prepara mejor en el propio lugar de la obra y las reparaciones pueden ser hechas con facilidad por obreros locales. Excepto proyectos muy sofisticados y sometidos a grandes esfuerzos, como es el caso de los recipientes de agua profunda, el control de calidad necesario en la preparación puede estar a cargo de un supervisor adiestrado al mando de obreros relativamente inexpertos.

Las siguientes recomendaciones específicas se basan en documentación compilada sobre el estado actual de este arte y en la propia evaluación del pa-

nel ad hoc de selectas aplicaciones del ferrocemento, tanto marinas como terrestres, que más adelante se detallan en este informe.

RECOMENDACIÓN 1: Investigación Exploratoria a la Más Amplia Escala de las Aplicaciones del Ferrocemento

El panel recomienda que el ferrocemento sea objeto de un amplio programa de investigación y desarrollo a fin de explorar todos sus usos potenciales. Es muy probable que dicha I & D conduzca a numerosas aplicaciones de provecho para los países en vías de desarrollo.

Algunas aplicaciones involucran análisis de laboratorio (por ejemplo, las interacciones entre alimentos almacenados y superficies de mortero); otras, pruebas estructurales; y aun otras, demostraciones y ensayos piloto. Las hay de índole tan especulativa que por el momento sólo se justifican estudios escritos. A esta labor pueden dedicarse instituciones de investigación, laboratorios de ingeniería, corporaciones capacitadas para llevar a cabo I & D, escuelas técnicas, universidades o individuos con capacidad de innovación. La exploración de estas aplicaciones del ferrocemento se presta excepcionalmente bien para ser realizada sobre el terreno en los países en desarrollo, si bien corresponde a los países industrializados la función de investigación.

Pese a que en este informe se destacan las aplicaciones menos complejas, el ferrocemento es susceptible de adaptarse también a tecnologías refinadas. Y así, en última instancia, bien podría terminarse por emplear este material en componentes industriales hechos con precisión. Un campo especialmente promisorio para investigación y desarrollo más avanzados, es reemplazar el ferrocemento con hormigón armado con pedazos de alambre, en el que pedazos cortos de alambre se colocan al azar, mezclados con la argamasa, en vez de la tela metálica.

A continuación se presenta una lista de las diversas aplicaciones que a juicio del panel merecen ser investigadas en detalle. Algunas de estas aplicaciones se discuten específicamente en las Recomendaciones 2 al 6. Se incluyen aquí con el propósito de hacer ver la amplia gama de los posibles usos del ferrocemento.

APLICACIONES POTENCIALES DEL FERROCEMENTO

- Barcos de carga y pesca
- Remolcadores y lanchas
- Puentes
- Desembarcaderos y marinas
- Depósitos permanentes para almacenar alimentos
- Almacenamiento de simiente (hortalizas, etc.)
- Almacenamiento de fécula, harina, azúcar
- Almacenamiento en silos
- Almacenamiento de aceite comestible (oliva, maní, semilla de algodón, palma, etc.)
- Almacenamiento de granos (arroz, trigo, maíz, sorgo, mijo, etc.)

Cubas de remojo de mandioca
Tanques de fermentación de cocoa, café, etc.
Tanques de enriamiento para sisal, yute, abacá, etc.
Depósitos de gas (para gas líquido y gas natural)
Torres de enfriamiento
Canales de aguas negras, piletas, tanques sépticos y otras facilidades de tratamiento
Alcantarillado
Equipos auxiliares para procesamiento de cueros
Cubas para teñir
Secadores de grano
Secadores de copra
Invernaderos, almacén de embalaje, y mesas secadoras
Plataformas para secar té, café, cocoa cocos, otros granos oleaginosos, pimienta, especias, etc.
Comederos y bebederos para ganado
Baños para ganado
Depósitos de agua potable y de irrigación
Cañería y conductos de irrigación
Hornos y chimeneas
Planchas o ripias para techos
Paneles decorativos y tejas planas
Empanelado de paredes
Pisos
Teléfono y postes para líneas de alta tensión
Revestimiento interior para túneles y minas
Estacas para sostener plantas tipo enredadera, tales como tomates, frijoles, etc. (resistentes a las termitas)
Reparación de baches (cuadrados de ferrocemento a la medida y colocados sobre el agujero)
Recintos para el tratamiento de vigas
Persianas y encofrado para uso en construcción estándar de hormigón armado

RECOMENDACIÓN 2: El Ferrocemento para Botes de Uso Local

El panel recomienda el ferrocemento como sustituto de materiales que se han venido usando hasta ahora en la construcción de botes de uso restringido y de línea tradicional. Esta aplicación merece amplia difusión, y a esta tarea bien podrían dedicarse los organismos de asistencia técnica. El elevado número de experimentos que se han llevado a cabo ya con éxito confirma su viabilidad técnica, pero es muy posible que en algunas regiones en vías de desarrollo se requieran pruebas de campo y demostraciones a fin de vencer cualquier resistencia local que pueda suscitarse respecto a innovaciones en la construcción de botes.

La Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO) y la Organización de las Naciones Unidas para Desarrollo Industrial (ONUDI) han tomado la iniciativa de introducir el ferrocemento en países en vías de desarrollo y demostrar su importancia en el contexto de desarrollo de dichos países. Hasta ahora, sin embargo, estos programas de asistencia técnica que utilizan ferrocemento sólo han tomado en cuenta buques pesqueros de rastreo de alta mar más grandes, con casco sofisticado de estilo occidental, con el propósito de aumentar su capacidad para la pesca comercial. La

pesca comercial a esta escala requiere una considerable organización terrestre para preservar, transportar y comercializar el producto, y el costo de botes pesqueros grandes representa una inversión que no puede afrontar un simple pescador que trabaja para subsistir. En este informe nos referimos a los barqueros de modo particular, ya sea que se dediquen a la pesca con fines comerciales o de subsistencia, a quienes beneficiaría disponer de pequeños botes a motor, de líneas sencillas, hechos de ferrocemento que, entre otras ventajas, fueran de bajo precio, larga vida y fáciles de reparar.

En un principio no tendría el mismo efecto en el desarrollo económico de un país mejorar este tipo de bote que si se introdujeran buques pesqueros de rastreo. No obstante, la rápida aceptación de botes de bajo costo de línea tradicional podría afectar en forma significativa el desarrollo económico debido al elevado número de botes involucrados y al notable aumento en su duracion.

Las singulares características del ferrocemento–bajo precio de los materiales, dureza, fácil mantenimiento–y reparación se prestan excepcionalmente bien a la fabricación de pequeños botes de uso local. Este material de construcción se aviene a la curvatura de la parte sumergida de los cascos de este tipo de embarcación. La fabricación de estos pequeños botes de trabajo podrían emprenderla localmente los obreros del lugar (pero bajo supervisión) quienes, por lo general, están disponibles a salarios bajos. Además, debido a que estos botes consisten mayormente en un casco y, por lo tanto, carecen de aditamentos costosos, el ahorro del constructor es máximo. Estos pequeños botes de trabajo operan por lo general en agua dulce, y en todo caso nunca lejos de tierra, por lo que sustentan menos tensión que los barcos de agua profunda y requieren una tecnología y control de calidad menos rigurosos. Por otra parte, los actuales botes de madera son a menudo tan pesados que un cambio a ferrocemento resultaría en botes de peso equivalente o mucho más livianos.

Puesto que todo diseño admite continuas mejoras, el de estos botes de la línea tradicional puede acusar notables mejoras a lo largo de los años. En particular, el ferrocemento se presta a las curvas complejas de los botes de madera, así como también a curvas más complejas aún que no son posibles de obtener con madera pero que mejorarían el rendimiento del bote.

El ferrocemento no es susceptible al ataque de teredos (gusanos de barco), carcoma y otros peligros de los trópicos. Además, debido a su inherente solidez, los botes de ferrocemento pueden ser motorizados en tanto que muchos botes de madera comparables no son lo suficientemente sólidos para resistir elementos impulsores mecánicos.

RECOMENDACIÓN 3: El Ferrocemento Aplicado a Instalaciones para Almacenar Alimentos

El panel opina que la urgente necesidad de preservar granos y otras cosechas de alimentos en países en vías de desarrollo justifica emprender extensos ensayos de campo sobre el uso del ferrocemento en la construcción de silos y

de depósitos de almacenaje. La existencia de prototipos idoneos sugiere que no se precisa más investigación que no sea estudios technoeconómicos y de diseño respecto a determinadas zonas.

En ambientes tropicales, las temperaturas elevadas y la humedad promueven el crecimiento de moho y la putrefacción de los productos alimenticios, destruyen materiales susceptibles a la humedad, tales como el cemento y los fertilizantes, y estimulan la degradación termal y ultravioleta de muchos productos. También los insectos, roedores y pájaros se ven enormemente afectados. Casi un 25%* de las cosechas anuales de alimentos en los países en desarrollo se malogran o son inaprovechables para el consumo a causa de defectos en la manipulación, métodos e instalaciones.

Los cientos de botes hechos de ferrocemento que flotan en todas las vías fluviales del mundo constituyen la mejor prueba de que este material es impermeable al agua, así como también la experiencia muestra que este material no se corroe fácilmente en los trópicos. Además, como se ha dicho ya, las estructuras de ferrocemento se hacen a partir de materiales y con mano de obra por lo general disponibles en los países en vías de desarrollo. No son necesarias ni maquinaria ni herramientas especiales.

La experiencia en Tailandia y en Etiopia muestra que se pueden construir localmente y a bajo costo silos para almacenar granos con sólo un supervisor y obreros inexpertos. Una versión simplificada de las técnica y materiales conocidos para la construcción de botes se utilizó en la construcción de silos. Las pérdidas anuales registradas en estos silos prototipo son menores que el 1%. Los roederos, pájaros e insectos no pueden ganar entrada al silo. Los silos de ferrocemento son herméticos, y así el aire que queda en su interior es rápidamente desprovisto del oxígeno por los granos que lo respiran, y los insectos (huevos, larvas, pupae o adultos) así como cualquier otro microorganismo aerobio que se haya podido introducir con el grano, son aniquilados.

La seguridad en el almacenaje de cereales y otros alimentos, tales como legumbres y granos oleaginosos, puede ayudar a los agricultores de los países en vías de desarrollo a tener más confianza en sus propios recursos y a la vez contribuir de manera importante a la economía del país y a la reserva de alimentos.

RECOMENDACIÓN 4: El Ferrocemento en la Tecnología de Alimentos

Teniendo en cuenta las propiedades, disponibilidad, facilidad de manufactura y confiabilidad del cemento, el panel asesor recomienda que los organismos de investigación hagan un esfuerzo serio e intenso para investigar el uso del ferrocemento como sustituto del acero—en especial el acero inoxidable—en la manufactura de por lo menos algunas piezas o unidades del equipo de procesamiento de productos alimenticios.

*Raymond E. Borton, ed., *Selected Readings To Accompany Getting Agriculture Moving Vol II* (Nueva York: Agricultural Development Council, 1966), p. 672.

Muchos alimentos–deteriorables en alto grado y que resultan irreversiblemente afectados por cambios de temperatura y contaminantes biológicos y químicos–se pierden para la humanidad por la falta de plantas rurales de procesamiento que preserven, transporten o procesen los productos alimenticios inmediatamente después de cosechados. En muchas áreas en vías de desarrollo, el costo excesivo de la construcción hace prohibitivo aun el uso del más simple equipo. Una gran parte de estos costos se debe al uso tradicional del acero inoxidable que, si bien de cualquier manera resulta muy costoso, lo es aún más en términos de divisas extranjeras cuando se debe recurrir a la importación.

Si se pudiera desarrollar equipo de ferrocemento (quizá pintado o barnizado), se mejorarían tal vez los niveles de nutrición y se podrían satisfacer las necesidades de pequeñas plantas de procesamiento de alimentos en países en vías de desarrollo que utilizan una alta proporción de mano de obra.

Algunas de las ventajas del empleo de ferrocemento en equipo para procesar alimentos son su (1) elaboración sobre todo con materiales locales; (2) solidez estructural y confiabilidad; (3) elaboración fácil, económica y versátil; (4) fácil mantenimiento y reparación; y (5) fácil transporte de las materias primas requeridas.

Es necesario emprender una investigación preliminar intensiva en especial en lo que se refiere a las propiedades sanitarias de las estructuras de ferrocemento y a su capacidad para llenar otros requisitos inherentes al procesamiento de alimentos. No obstante, el panel está convencido de que vale la pena hacer un esfuerzo en este sentido en vista de que el ferrocemento se presta al parecer para (1) el procesamiento con miras a la preservación de frutas y legumbres; (2) cubas de fermentación de salsas de pescado, salsa de soya, cerveza, vino, etc.; (3) tanques o cubas para depósito de jugos, aceite vegetal, suero de la leche o agua potable; y (4) multitud de otros fines–desecadores por pulverización de leche, desecadores de copra, cocinas y hornos a gas, lecherías, cámaras frigoríficas y mataderos.

RECOMENDACIÓN 5: El Ferrocemento para Techos de Bajo Costo

El panel considera que el ferrocemento puede resultar apropiado como material para techos de bajo costo en países en vías de desarrollo. Los laboratorios de ciencias aplicadas en los países en desarrollo y las agencias que patrocinan la investigación aplicada debieran considerar seriamente la realización de estudios tecnoeconómicos y pruebas de campo sobre esta aplicación del ferrocemento.

Contar con un albergue adecuado es una necesidad esencial del ser humano, y en todo albergue el techo constituye el elemento básico. Pese a esto, los materiales actuales no satisfacen los requisitos inherentes a los techos. Más países de los 80 en vías de desarrollo en el mundo padecen escasez de viviendas como resultado del aumento de la población, la migración interna y algunas veces a causa de la guerra o desastres naturales. En la mayoría de moradas de los países en vías de desarrollo un techo durable representa el gasto principal. Los techos

hechos con materiales locales baratos, como, por ejemplo, hierba o caña o productos derivados de la tierra (arena, barro, roca), son por lo general poco firmes y de poca duración. Un problema secundario es contar con estructuras de soporte adecuadas y duraderas. En algunas zonas, los escasos soportes de madera se debilitan por efecto de la pudrición y del ataque de insectos.

El ferrocemento representa una solución potencial al problema de techos debido a su bajo costo relativo, durabilidad, resistencia a la intemperie y, en particular, por su versatilidad. En contraste con la mayoría de los materiales convencionales, el ferrocemento puede moldearse fácilmente en forma de cúpulas, bóvedas, perfiles extruidos, superficies planas, etc. Su fácil elaboración, incluso en zonas rurales, por obreros del lugar bajo supervisión y con materiales nacionales, lo calificaría de excelente medio para la manufactura *in situ* de tejas pequeñas o grandes (ripias) y de otros elementos de techar. Dondequiera que las vigas de madera fuesen costosas, se podrian hacer vigas de ferrocemento en reemplazo de las estructuras de madera que sostienen los elementos de manufactura nacional que recubren el techo. Su uso más económico, sin embargo, parecería ser en techos de dimensión relativamente grande.

Pese a sus excelentes cualidades, no se utiliza ferrocemento con la debida frecuencia. Su uso, en especial en lo que atañe a los países en vías de desarrollo, debe estar precedido de más investigación y de experimentos de diseño y de técnicas de producción que se ajusten a circunstancias de mano de obra poco calificada.

RECOMENDACIÓN 6: El Ferrocemento en Campañas de Socorro ante Desastres

El panel recomienda que las organizaciones encargadas del socorro en caso de desastre presten cuidadosa consideración al ferrocemento. Esta recomendación abarca todas las aplicaciones posibles de este material consideradas por el panel para el caso de los países en vías de desarrollo.

Es bien sabido que inmediatamente después de un incendio, inundación, sequía o terremoto es urgente contar con alimentos, albergues y facilidades de sanidad pública. A menudo el transporte se interrumpe a consecuencia de la destrucción de caminos, puentes, buques y pistas de aterrizaje. La zona del desastre se ve así desprovista de los materiales de construcción convencionales porque éstos no pueden llegar a su destino; en el caso del ferrocemento, sin embargo, el transporte de sus elementos básicos es fácil o, en su defecto, éstos pueden hallarse localmente.

La versatilidad característica del ferrocemento tiende también a reducir los problemas logísticos de abastecimiento: tela metálica, cemento, arena y agua pueden hacer las veces del metal utilizado para reforzar techos, de cemento para paredes, de madera o de plástico para la construcción de albergues o clínicas, de asfalto para plataformas de aterrizaje y despegue de helicópteros, de acero para puentes y así sucesivamente. Más aún, la mayoría de las estructuras

de ferrocemento, si bien hechas para remediar una situación de emergencia, durarán hasta mucho después que ésta haya pasado.

En la opinión del panel, se podría utilizar ferrocemento en lugares de desastre con múltiples finalidades:

- Transporte, desde simples botes hasta barcazas, muelles, dársenas, plataformas para aterrizaje y despeque de helicópteros, y puentes flotantes simples o pasaderas cortas, así como también en la reparación de caminos.
- Almacenamiento de alimentos, en depósitos de rápido diseño y construcción para guardar provisiones de emergencia.
- Albergues de emergencia, como, por ejemplo, los de techo semicircular o curvado, que son fáciles de erigir y muy eficaces.
- Servicios de sanidad pública, tales como letrinas y clínicas, construidos con techos de ferrocemento y paredes tipo estuco de la misma tela metálica y argamasa.

Con el fin de capacitar en el uso de ferrocemento en campañas de socorro, se podrían organizar demostraciones, durante simulacros de emergencias, en beneficio de organizaciones nacionales e internacionales, y adiestrar a obreros en las aplicaciones del ferrocemento bajo condiciones de emergencia y en la supervisión de trabajadores locales en la escena del desastre.

RECOMENDACIÓN 7: Un Comité de Coordinación

El panel propone el establecimiento de un *Comité Multidisciplinario para la Cooperación Internacional en la Investigación y Desarrollo de Ferrocemento para Países en Vías de Desarrollo*, compuesto por expertos provenientes de países que hubieran logrado un alto grado de competencia en el uso de ferrocemento, incluyendo la Unión Soviética y la República Popular de China. El comité podría establecerse bajo los auspicios de organizaciones, tales como ONUDI y FAO, que ya cuentan con grupos similares respecto a otras tecnologías.* No existe un grupo que esté a la disposición de organismos de países en desarrollo que soliciten asesoría competente; no obstante, es necesario contar con un tal comité internacional de expertos por lo menos hasta disponer de patrones adecuados y salvaguardias que reglen la construcción con ferrocemento**—en particular respecto a sus usos en aguas profundas. Dicho comité ayudaría a evitar que se repita, como en años recientes, el establecimiento de empresas improvisadas de ferrocemento.

*Por ejemplo, los "Grupos Asesores de Trabajo sobre Investigación de Fibra Dura" de FAO, y los diversos "Grupos de Trabajo de Expertos" de ONUDI.

**Por ejemplo, la Society of Naval Architects and Marine Engineers está dedicada actualmente a formular especificaciones para el diseño de embarcaciones de ferrocemento; y Lloyd's Register of Shipping y American Bureau of Shipping tienen en marcha tareas similares.

El comité propuesto debiera tener por lo menos las siguientes funciones:

1. Mejorar la comunicación y la fertilización cruzada entre todos los campos de especialización técnica involucrados (ingeniería, química, arquitectura, agricultura, bromatología, construcción, pesca, construcción de botes).
2. Convocar reuniones que propicien la comunicación entre expertos y técnicos.
3. Proporcionar las pautas y servir de catalizador a las facilidades para el adiestramiento en ferrocemento descritas en la Recomendación 8.

Mediante estas acciones, el comité promovería la introducción racional y efectiva de la tecnología del ferrocemento en los países en vías de desarrollo y estimularía el avance de la investigación y el desarrollo de modo eficiente y productivo.

RECOMENDACIÓN 8: Facilidades para el Adiestramiento en Ferrocemento de Alcance Internacional

El panel recomienda el establecimiento de facilidades para el adiestramiento en tecnología y aplicaciones del ferrocemento de alcance internacional.

El panel está firmemente convencido de que el aprovechamiento potencial del ferrocemento justifica que dichas facilidades se ubiquen en, o cerca de, países en vías de desarrollo. La seria escasez actual de personal adiestrado que preste servicios de asistencia o asesoría en proyectos de construcción a base de ferrocemento podría ser un factor limitativo del establecimiento de programas de alta calidad.

En la actualidad hay dos programas que se llevan a cabo en el Pacífico del Sur que merecen atención y ser tomados como ejemplo. En Nueva Zelanda, el gobierno costea el establecimiento de una escuela para el adiestramiento en construcción marina a base de ferrocemento, y ONUDI auspicia un programa en Fidji, mediante el cual los habitantes de una aldea se trasladan hasta un taller central de construcción de embarcaciones y participan en la construcción de un bote para la "aldea".

Las escuelas para adiestramiento en ferrocemento propuestas por el panel deberán: (1) adiestrar personal de los países en vías de desarrollo en el establecimiento de facilidades de construcción, tanto marinas como terrestres, y en la supervisión de los proyectos de construcción; (2) capacitar personal para que se encargue de establecer escuelas de adiestramiento en el campo o cualquier otra localidad; y (3) preparar materiales audiovisuales.

Estas escuelas de adiestramiento en ferrocemento podrían muy bien ser implantadas en instituciones técnicas ya existentes o, en su defecto, establecerse como entidades separadas.

RECOMENDACIÓN 9: Un Servicio Internacional de Información sobre Ferrocemento

En consideración a que el interés en el ferrocemento va en aumento, el panel recomienda el establecimiento de un servicio internacional encargado de compilar y diseminar información sobre la ciencia del ferrocemento. Dicho servicio evitaría una duplicación innecesaria de investigación y desarrollo, y aseguraría que todo país interesado en vías de desarrollo tenga cabal conocimiento de la experimentación relevante que se realiza con ferrocemento en otras partes del mundo.

El servicio de información podría establecerse en el seno de una institución académica o de investigación que ya posea competencia y programas en curso sobre la tecnología del ferrocemento.

El servicio de información debiera tener cuando menos las siguientes funciones:

1. Mantener un banco de información y servicio de referencia de solicitudes de datos sobre ferrocemento.
2. Diseminar información sobre los esfuerzos que se realizan en investigación y desarrollo y sobre los avances y aplicaciones de la tecnología del ferrocemento.
3. Ayudar a los países en desarrollo a identificar empresas y consultores con experiencia en ferrocemento, en especial aquéllos con experiencia en los países en vías de desarrollo.

Résumé et Recommandations

Le ferrociment est une forme de béton renforcé, à usages multiples, composé de ciment, de treillis métallique, de sable et d'eau, qui possède des qualités uniques de résistance et d'utilité. Sa fabrication demande un minimum de main d'oeuvre spécialisée, et emploie des matériaux que l'on peut se procurer facilement. Utilisé avec succès pour la construction navale, il est ou peut être aussi employé à de nombreux usages dans l'agriculture, l'industrie et la construction de logements.

Le ferrociment est un matériau qui convient particulièrement aux pays en voie de développement pour les raisons suivantes:

- Les produits de base qui le composent se trouvent dans la plupart des pays.
- Il peut être façonné en n'importe quelle forme, ou a peu près, selon les besoins de l'utilisateur; les formes traditionnelles peuvent être reproduites et souvent améliorées. Bien fabriqué, il est plus durable que la plupart des bois et beaucoup moins onéreux que les aciers importés, et peut être utilisé à la place de ces matériaux dans de nombreux cas.
- L'utilisation du ferrociment ne nécessite pas un long apprentissage et ses techniques sont, pour beaucoup, des techniques courantes dans les pays en voie de développement. La construction en ferrociment n'exige pas d'équipement et d'outillage lourds; elle emploie une main d'oeuvre nombreuse, se fait de préférence sur place, et peut être facilement réparée par la main d'oeuvre locale. Sauf dans le cas de modèles très élaborés ou très travaillés, comme ceux des navires hauturiers, un contremaître spécialisé peut assurer le contrôle de qualité necessaire et utiliser ainsi pour la fabrication une main d'oeuvre assez peu qualifiée.

Les recommandations spécifiques suivantes sont basées sur la documentation–analysée plus loin en détail–relative à l'état actuel de développement de cet art, et sur l'évaluation faite, par la Commission, de certaines applications du ferrociment aussi bien sur terre qu'à des usages maritimes.

PREMIÈRE RECOMMANDATION: Recherche concernant toutes les applications possibles du ferrociment.

La Commission recommande que le ferrociment fasse l'objet d'un programme étendu de recherche et de développement, visant à explorer toutes ses utilisations potentielles, recherche et développement qui aboutiront vraisemblablement à un grand nombre d'applications présentant un grand intérêt pour le Tiers Monde.

Certaines applications nécessitent des analyses effectuées en laboratoire (par exemple, l'action réciproque des aliments entreposés et des surfaces de mortier); d'autres, des épreuves de structure; d'autres encore, des démonstrations et des essais-pilotes. D'autres applications sont de nature si spéculative que seules des études théoriques sont justifiées à l'heure actuelle. Des institutions de recherche, des laboratoires techniques, des sociétés ayant les moyens de faire de la recherche et du développement, des écoles techniques, des universités ou des spécialistes capables d'innover peuvent s'en charger. Bien que le présent rapport présente essentiellement les utilisations les plus simples du ferrociment, ce matériau peut être adapté à une technologie plus complexe. Il se peut qu'en fin de compte, il soit surtout utilisé pour la fabrication de pièces usinées de précision. Le remplacement du ferrociment par du béton auquel aura été incorporée au lieu de treillis une armature en débris de fil métallique est un domaine d'utilisation plein de promesses pour des services de recherche et de développement, à un stade plus avancé.

Nous énumérons, ci-dessous diverses applications particulières qui, selon la Commission, méritent tout particulièrement d'être étudiées. Quelques-unes d'entre elles font l'objet d'une discussion spécifique dans les Recommandations 2 à 6. Elles figurent sur la liste qui suit pour donner une idée de la gamme des utilisations possibles du ferrociment.

APPLICATIONS POTENTIELLES DU FERROCIMENT

- Bateaux de pêche et cargos
- Remorqueurs et péniches
- Ponts
- Bassins et marinas
- Dépôts permanents pour l'entreposage des denrées alimentaires
- Entrepôts pour les semences (légumes, etc.)
- Entreposage en silos
- Entreposage des huiles comestibles (olive, arachide, graines de coton, palme, etc..)
- Entreposage des grains (riz, blé, maïs, sorgho, millet, etc...)
- Cuves de trempage pour le manioc
- Réservoirs pour la fermentation du cacao, du café, etc...
- Réservoirs pour le rouissage du sisal, du jute, du chanvre, etc..
- Réservoirs à gaz (liquide et naturel)
- Tours de réfrigération
- Cuves d'épandage, lagunes, fosses septiques et autres installations de traitement des immondices
- Gouttières
- Fosses de tannage
- Cuves à teinture
- Séchoirs à grains

Séchoirs à copra
Auges et abreuvoirs pour le bétail
Réservoirs pour le bain du bétail
Entreposage d'eau potable et d'eau pour l'irrigation
Canalisations et conduits d'irrigation
Fours et cheminées
Plaques ou bardeaux pour les toitures
Panneaux et tuiles décoratifs
Panneaux pour le revêtement des murs
Planchers
Poteaux pour les fils téléphoniques et électriques
Revêtement intérieur de tunnels, de galeries de mines
Echalas et tuteurs pour les tomates, les haricots, etc.. à cause de leur résistance aux termites
Réparation des fondrières (cubes de ferrocimente ajustés et posés dans les fondrières)
Enclos pour le traitement des grumes
Volets et coffrage utilisé pour la construction standard en beton
Serres, conserveries et tables de séchage, séchoirs pour le thé, le café, le cacao, les noix de coco, les autres graines oléagineuses, le poivre, les épices, etc..

DEUXIÈME RECOMMANDATION: Utilisation du ferrociment pour la construction d'embarcations indigènes.

La Commission recommande le ferrociment en tant que produit de remplacement des matériaux utilisés à l'heure actuelle pour la construction des embarcations indigènes aux formes traditionnelles. Cette utilisation mérite d'être très largement répandue, tâche dont pourraient se charger les organismes d'assistance technique. La longue liste des essais satisfaisants qui ont été faits confirme la fiabilité de cette application du ferrociment, mais il sera peut-être nécessaire, pour surmonter la résistance opposée par les populations locales à cette nouvelle méthode de construction navale, de procéder à des essais et à des démonstrations sur place.

L'Organisation des Nations Unies pour l'Alimentation et l'Agriculture (FAO) et l'Organisation des Nations Unies pour le Développement Industriel (UNIDO) ont pris l'initiative d'introduire le ferrociment dans les pays du Tiers Monde, et de démontrer son importance dans le contexte d'un pays en voie de développement. Jusqu'alors, cependant, ces projets d'assistance technique utilisant le ferrociment concernaient des chalutiers de haute mer ayant des coques compliquées de style occidental, leur objectif étant d'accroître la capacité de la pêche commerciale. A cette échelle, la pêche commerciale nécessite à terre une importante installation qui permette de mettre en conserve, de transporter et de vendre le produit de la pêche, et le coût des grands chalutiers représente un investissement que ne peuvent pas se permettre les pêcheurs dont la prise est destinée essentiellement à leur alimentation. Dans le présent rapport, nous nous occupons du pêcheur individuel–qu'il consomme ou qu'il vende sa prise–qui bénéficierait du coût peu élevé, de la solidité et de la réparation facile d'un petit bateau en ferrociment ayant la même forme et la même propulsion que ceux auxquels il est habitué.

Cette amélioration des embarcations traditionnelles n'aura pas, dans l'immédiat, le même effet sur le développement économique que l'introduction de chalutiers. Cependant, l'acceptation facile de bateaux peu coûteux, aux formes traditionelles, pourrait contribuer de facon significative au développement économique en raison de l'importance de la flotte de pêche qui pourrait ainsi être constituée.

Les propriétés exceptionnelles du ferrociment–coût peu élevé des matières premières, résistance, facilité d'entretien–en font un matériau particulièrement adapté à la fabrication de petites embarcations indigènes. Les coques recourbées de ces dernières peuvent être facilement reproduites avec ce matériau. Des petits bateaux en ferrociment pourraient être construits sur place par des ouvriers locaux, que l'on trouve généralement aisément et à peu de frais, sous la supervision d'un contremaître. Etant donné que ces embarcations comprennent essentiellement une coque et n'ont pas, par conséquent, d'installations coûteuses, le constructeur réalise un maximum d'économies. Du fait qu'elles ne s'éloignent jamais beaucoup de la rive et naviguent le plus souvent en eau douce, les petites embarcations sont soumises à moins d'épreuves que les navires hauturiers, et ne nécessitent pas une technologie et un contrôle de qualité aussi rigoureux. En outre, les embarcations en bois utilisées actuellement sont souvent si lourdes que des bateaux en ferrociment pouvraient être d'un poids équivalent ou même inférieur.

Etant donné que le dessin d'un bateau peut être amélioré progressivement, la forme d'une embarcation de type traditionnel pourrait aussi être peu a peu améliorée. En particulier, l'utilisation du ferrociment permet de reproduire les courbes complexes des bateaux en planches de bois, et de produire les courbes plus complexes que ne permet pas la construction en bois, mais amélioreraient la performance de l'embarcation.

Le ferrociment n'est pas attaqué par les tarets, la pourriture du bois et autres fléaux des tropiques; de plus, les bateaux en ferrociment ont une résistance inhérente suffisante pour pouvoir être équipés d'un moteur; certaines embarcations analogues, en bois, ne sont pas assez résistantes pour cela.

TROISIÈME RECOMMANDATION: Utilisation du ferrociment pour l'entreposage des produits alimentaires.

La Commission estime que le besoin urgent de conserver les grains et autres produits alimentaires dans les pays en voie de développement justifie que l'on y procède sur place à des essais expérimentaux extensifs de l'utilisation du ferrociment pour la construction de silos ou de réservoirs pour leur entreposage. Les prototypes efficaces déjà construits donnent à penser qu'il suffirait, pour cela, de peu de recherche, en dehors d'études techno-économiques et de plans d'entrepôts pour des localités déterminées.

Dans les régions tropicales, les hautes températures et l'humidité favorisent la moisissure et la pourriture des produits alimentaires, détruisent les matériaux sensibles à l'humidité, tels que le ciment et les engrais, et facilitent la dégradation par la chaleur et les rayons ultra-violets d'un grand nombre de pro-

duits. Les insectes, les rongeurs et les oiseaux causent aussi de graves dommages. On estime que, dans le Tiers Monde, vingt-cinq pour cent des récoltes alimentaires sont, chaque année, rendus impropres à la consommation ou détruits à cause d'une manutention, de méthodes d'entreposage et d'installations défectueuses.*

Les centaines de bateaux en ferrociment qui naviguent sur les voies navigables dans le monde entier démontrent la totale étanchéité de ce matériau; d'autres essais ont prouvé que le ferrociment se corrode très difficilement dans les régions tropicales. En outre, comme nous l'avons déjà indiqué, les structures en ferrociment sont fabriquées à l'aide de matériaux et de main-d'oeuvre qui existent généralement dans les pays en voie de développement. Elle ne nécessite pas d'equipement ni d'outils spéciaux.

Les expériences faites en Thaïlande et en Ethiopie ont montré que l'on peut construire sur place des silos à grains à très peu de frais en utilisant seulement un contremaître et des ouvriers non spécialisés. Une version simplifiée des máteriaux et des techniques employées pour la construction de bateaux en ferrociment a été utilisée pour construire les silos. Dans les prototypes des silos, la perte measurable est inférieure à un pour cent par an. Les rongeurs, les oiseaux et les insectes ne peuvent y accéder. Ces silos en ferrociment étant imperméables à l'air, l'air qui y est contenu est rapidement privé de son oxygène par la respiration des grains, et les insectes qui s'y trouvent (oeufs, larves, chrysalides ou adultes), ainsi que tous autres organismes vivants qui pourraient y être introduits avec le grain sont détruits.

Ce moyen efficace d'entreposer les grains et autres produits alimentaires tels que les légumineuses et les graines oléagineuses, peut aider les agriculteurs du Tiers Monde à devenir plus indépendants, et pourrait contribuer de facon significative à l'économie d'un pays et permettre d'accroître ses réserves alimentaires.

QUATRIÈME RECOMMANDATION: Utilisation du ferrociment dans la technologie des aliments

En raison des propriétés, de la disponibilité, de la fabrication facile et de la solidité du ferrociment, la Commission recommande ques le organismes de recherche fassent un effort sérieux et de grande envergure pour étudier le remplacement possible de l'acier–notamment l'acier inoxydable–par le ferrociment dans la fabrication d'au moins quelques éléments de base de l'équipement utilisé pour le traitement des produits alimentaires.

Un grand nombre de produits alimentaires extrêmement périssables, affectés de facon irréversible par les changements de température et les contaminents biologiques et chimiques, ne peuvent pas être utilisés pour les besoins humains faute d'installations dans les régions rurales pour conserver, achemi-

*Raymond E. Borton. *Selected Readings To Accompany Getting Agriculture Moving.* Vol II. New-York: Agricultural Development Council, 1966. p. 672.

ner ou traiter ces denrées peu après leur récolte. Dans de nombreuses régions du Tiers Monde, le coût élevé de la construction interdit l'utilisation d'équipement manufacturé même simple. Ces coûts sont dus, pour une grande part, à l'utilisation de l'acier, onéreux en tout état de cause, mais tout particulièrement en terme de devises étrangères quand il faut l'importer.

Si l'on peut construire en ferrociment (éventuellement couvert d'un revétement) l'équipement pour le traitement des denrées alimentaires, celà peut permettre d'améliorer le niveau de nutrition et se prêter à la petite industrie de traitement de ces denrées dans les pays du Tiers Monde, qui utilise une main d'oeuvre nombreuse.

Le ferrociment présente, entre autres, les avantages suivants pour l'équipement de traitement des denrées alimentaires: 1) sa construction utilisant essentiellement des matériaux d'origine locale; 2) sa résistance structurelle et sa solidité; 3) la facilité, le coût peu élevé de sa construction et sa versatilité; 4) son entretien et sa réparation faciles; 5) ses matières premières faciles à transporter.

Des recherches extensives en laboratoires sont nécessaires, notamment en vue d'étudier les propriétés sanitaires des structures en ferrociment et leur aptitude à satisfaire aux autres conditions exigées pour le traitement des produits alimentaires. Néanmoins, la Commission estime que l'effort mérite d'être fait, étant donné que le ferrociment peut, apparemment, être utilisé pour

1. le traitement des fruits et des légumes en vue de leur préservation;
2. les cuves de fermentation pour les sauces de poisson, la sauce de soja, la bière, le vin, etc.;
3. les réservoirs pour l'entreposage des jus de fruits, de l'huile végétale, du petit lait ou de l'eau potable; et
4. beaucoup d'autres usages—vaporisateurs/sécheurs pour la concentration du lait, séchoirs a copra, cuisinières ou fours, laiteries, chambres de congélation et abattoirs.

CINQUIÈME RECOMMANDATION: Utilisation du ferrociment pour les toitures à bon marché.

La Commission pense que le ferrociment pourrait servir à fabriquer des toitures à bon marché dans les pays en voie de développement. Les laboratoires de sciences appliquées, dans les pays en voie de développement, et les organismes d'assistance technique devraient sérieusement envisager de faire, dans ce domaine, des essais sur place et des études techno-économiques.

Un abri adéquat est un besoin essentiel des humains, et un toit est l'élément fondamental de l'abri. Mais les matériaux qu'on utilise actuellement ne permettent pas de satisfaire la demande de toitures. Les quatre-vingt et quelque pays en voie de développement souffrent tous d'une pénurie d'habitations due à l'accroissement démographique, à la migration intérieure et, parfois à la guerre ou à une catastrophe naturelle. Dans les pays en voie de développe-

ment, un toit durable est le plus important facteur du coût de la plupart des habitations. Les toits en matériaux locaux peu onéreux tels que l'herbe ou les roseaux (chaume) ou les produits de la terre (sable, boue, pierre) sont habituellement peu sûrs et peu durables. Un problème secondaire est le besoin de charpentes adéquates et durables. Dans certaines régions, les rares charpentes en bois sont affaiblies par la putréfaction et rongées par les insectes.

Le ferrociment constitue une solution possible aux problèmes que posent les toitures, grâce à son coût peu élevé, à sa solidité, à sa résistance à la chaleur et à l'humidité et particulièrement à sa facilité d'utilisation. Contrairement à la plupart des matériaux habituellement utilisés, le ferrociment peut être facilement façonné en dômes, en arcs, en formes semblables à celles qu'on obtient avec du métal refoulé, en surfaces planes ou en surfaces de forme libre. Du fait que le ferrociment est facile à fabriquer, même dans les régions rurales, par de la main d'oeuvre locale guidée par un contremaître, qui utilise des matériaux d'origine locale, il semble qu'il soit le matériau idéal pour la construction sur place de petites ou grandes tuiles (bardeaux), ou de tous autres éléments de toiture. Dans les pays où le bois de charpente est très cher, des poutres de ferrociment pourraient être fabriquées sur place pour remplacer les charpentes de bois utilisées pour supporter les toitures de type local. Il semble, toutefois, que ce soit pour les toits à assez grande portée que son emploi est le plus économique.

Malgré les avantages qu'il semble présenter pour cet usage, le ferrociment n'est pas utilisé de façon courante pour les toitures. Avant qu'il puisse l'être, notamment dans les pays en voie de développement, il est indispensable que des recherches et études plus approfondies sur les formes et techniques de production susceptibles d'être utilisées pour sa production par une main d'oeuvre non spécialisée soient entreprises.

SIXIÈME RECOMMANDATION: Utilisation du ferrociment pour la réparation des dommages causés par les catastrophes.

La Commission recommande que les organismes chargés de venir en aide aux sinistrès considèrent sérieusement l'utilisation éventuelle du ferrociment.

Cette recommandation combine toutes les applications possibles du ferrociment envisagées par la Commission dans les pays en voie de développement.

Après les incendies, les inondations et les tremblements de terre, il existe un besoin urgent de produits alimentaires, d'abris et d'installations sanitaires. Les transports sont souvent interrompus par la destruction de routes, de ponts, de bateaux et de pistes d'aterrissage. Il se peut que les matériaux de construction habituels se trouvent en dehors des régions sinistrées et qu'il ne soit pas possible de les amener sur place, alors que les composants du ferrociment sont plus facilement transportables ou sont peut-être disponibles sur place.

Les multiples possibilités d'utilisation du ferrociment réduisent aussi les problèmes de logistique; du treillis métallique, du ciment, du sable et de l'eau

peuvent se substituer au métal utilise pour renforcer les toitures, au ciment pour la construction des murs, au bois ou aux matières plastiques pour les abris ou les cliniques, à l'asphalte pour les point d'aterrissage des hélicoptères, à l'acier pour les ponts, etc.. De plus, la plupart des structures en ferrociment, quoique bâties pour parer à une situation critique, durera plus longtemps une fois la situation redevenue normale.

La Commission estime que le ferrociment pourrait être utilisé sur place en cas de catastrophe, à des fins multiples:

- Moyens de transport, de la simple embarcation à la peniche; entrepôts; ports pour les petites embarcations; points d'aterrissage pour hélicopteres et ponts flottants ou passerelles simples, ainsi que pour la réparation des routes.
- Entrepôts pour les produits alimentaires, adaptés rapidement aux besoins locaux et construits rapidement pour les denrées alimentaires destinées à faire face à des situations d'urgence.
- Abris provisoires comme, par exemple, les toitures du type "quonset", qui sont faciles à mettre en place et extrêmement efficaces.
- Installations sanitaires telles que latrines et cliniques construites avec des toits en ferrociment et des murs de type "stuc", également en mortier et treillis métallique.

Pour préparer l'utilisation du ferrociment en périodes de catastrophes, des démonstrations dans des cas d'urgence simulés pourraient être organisées par des organismes de secours national ou international; et des équipes de contremaîtres spécialisés dans le travail en ferrociment pourraient être formées, pour encadrer les travailleurs locaux sur les lieux du désastre, aux applications de ce matériau en cas d'urgence.

SEPTIÈME RECOMMANDATION: Constitution d'un Comité de coordination ou Groupe de travail.

La Commission recommande que soit créé un *Groupe de travail* multidisciplinaire *pour la coopération internationale dans la recherche et le développement de l'utilisation du ferrociment dans les pays en voie de dévelloppement*, composé d'experts venus de pays qui ont atteint une très grande compétence dans l'emploi du ferrociment, dont l'Union soviétique, la République populaire de Chine, les pays d'Europe et d'Amérique du Nord. Le Groupe de travail pourrait être créé sous les auspices d'organisations comme l'UNIDO et la FAO, qui ont déjà des Groupes analogues pour d'autres technologies.* Il n'y a pas actuellement de Groupe à la disposition des pays qui ont besoin de conseils éclairés; pourtant, un tel Comite international d'experts est indispensable, tout au moins jusqu'a ce qu'on dispose de normes et de règles d'application

*Par exemple, a la FAO: "Advisory Working Party on Hard Fibre Research," et à l'UNIDO: divers "Expert working groups."

pour la construction en ferrociment,* notamment pour les utilisations en eau profonde. Ce Comité pourrait empêcher que se reproduise l'expérience malheureuse qu'ont faite récemment plusieurs entreprises de ferrociment.

Le Groupe de travail devra au moins être charge de:

1. Assurer une meilleure communication et une coopération fructueuse entre toutes les disciplines interessées (génie, chimie, architecture, agriculture, technologie de l'alimentation, construction, pêche, construction navale).
2. Organiser des réunions qui permettent aux experts et aux techniciens de se rencontrer, et
3. Diriger et catalyser les installations de formation aux techniques du ferrociment décrites dans la huitième recommandation.

Le Groupe de travail pourra ainsi contribuer à l'introduction rationnelle et efficace de la technologie du ferrociment dans les pays en voie de développement, et encourager l'évolution efficace et éclairée de la recherche et du developpement.

HUITIEME RECOMMANDATION: Création de centres de formation pratique à la technologie du ferrociment.

La Commission recommande que soient créés des centres internationaux de formation pratique à la technologie du ferrociment et à son application.

La Commission est convaincue que les possibilités d'utilisation du ferrociment justifient l'installation de ces centres dans les pays en voie de développement ou à proximité de ces pays. La grave pénurie actuelle de personnel qualifié pour aider à élaborer et à mettre en oeuvre des projets de construction en ferrociment risque de limiter l'élaboration de programmes de haute qualité.

Deux programmes réalisés dans le Pacifique Sud méritent d'être étudiés et réalisés ailleurs. En Nouvelle-Zélande, le Gouvernement finance une école pratique pour la construction navale en ferrociment. L'UNIDO exécute a Fidji un programme par lequel les habitants de villages se rendent dans un chantier naval central, ou tous travaillent à la construction d'un bateau pour chaque village.

Les centres pratiques dont la création est proposée par la Commission devront:

1. Former les contremaîtres des pays en voie de développement et leur apprendre à construire des chantiers de constructions, tant sur terre que navales, utilisant le ferrociment, et à contrôler les projets de construction;

*Par exemple, la "Society of Naval Architects and Marine Engineers" est en train de formuler les spécifications pour le dessin de bateaux en ferrociment"; Lloyd's Register of shipping" et l'"American Bureau of Shipping" travaillent actuellement à des études concernant le ferrociment.

2. Préparer le personnel à installer des écoles pratiques au niveau national et local; et

3. Produire du matériel d'enseignement audiovisuel.

Ces centres de formation pourraient venir se greffer sur les écoles techniques existantes, ou crées en tant qu'entités separées.

NEUVIÈME RECOMMANDATION: Un service international d'information sur le ferrociment.

En raison de l'intérêt croissant que suscite le ferrociment, la Commission recommande que soit créé un service international qui serait chargé de réunir et de disséminer les informations relatives à la science du ferrociment. Ce service éviterait la duplication inutile de la recherche et du développement et assurerait que les pays intéressés sont informés de toutes les expériences faites ailleurs dans le monde dans le domaine du ferrociment, susceptibles de les intéresser.

Le service d'information pourrait être adjoint à une institution académique ou de recherche qui possède déjà une certaine connaissance du sujet et des cours de technologie du ferrociment.

Il devrait avoir au moins les fonctions suivantes:

1. Tenir à jour une banque d'informations et comporter un service de réponse aux demandes d'informations sur le ferrociment;

2. Disséminer les informations relatives à la recherche et au développement et aux progrès de la technologie du ferrociment ainsi qu'aux essais d'application de ce matériau; et

3. Aider les pays en voie de développement à trouver les sociétés et les consultants spécialisés dans le ferrociment, notamment ceux qui en ont fait l'expérience dans les pays en voie de développement.

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22. Guayule: An Alternative Source of Natural Rubber. 1977. 80 pp. Describes a little-known bush that grows wild in deserts of North America and produces a rubber virtually identical with that from the rubber tree. Recommends funding for guayule development. NTIS Accession No. PB 264-170.

23. Resource Sensing from Space: Prospects for Developing Countries. 1977. 203 pp. An examination of current and prospective applications of interest to developing countries, certain implications for long-term governance of a remote sensing system, and desirable technical cooperation initiatives to diffuse user capabilities. NTIS Accession No. PB 264-171. (French language edition available from BOSTID or through NTIS, Accession No. PB 80-168-693.)

25. Tropical Legumes: Resources for the Future. 1979. 331 pp. Describes plants of the family Leguminosae, including root crops, pulses, fruits, forages, timber and wood products, ornamentals, and others. NTIS Accession No. PB 298-423.

26. Leucaena: Promising Forage and Tree Crop for the Tropics. 1977. 118 pp. Describes *Leucaena leucocephala,* a little-known Mexican plant with vigorously growing, bushy types that produce nutritious forage and organic fertilizer as well as tree types that produce timber, firewood, and pulp and paper. The plant is also useful for revegetating hillslopes and providing firebreaks, shade, and city beautification. NTIS Accession No. PB 268-124.

27. Firewood Crops: Shrub and Tree Species for Energy Production. 1980. 237 pp. Examines the selection of species suitable for deliberate cultivation as firewood crops in developing countries.

28. Microbial Processes: Promising Technologies for Developing Countries. 1979. 198 pp. Discusses the potential importance of microbiology in developing countries in food and feed, plant

nutrition, pest control, fuel and energy, waste treatment and utilization, and health. NTIS Accession No. 80-144-686.

29. Postharvest Food Losses in Developing Countries. 1978. 202 pp. Assesses potential and limitations of food loss reduction efforts; summarizes existing work and information about losses of major food crops and fish; discusses economic and social factors involved; identifies major areas of need; and suggests policy and program options for developing countries and technical assistance agencies. NTIS Accession No. PB 290-421.

30. U.S. Science and Technology for Development: Contributions to the UN Conference. 1978. 226 pp. Serves the U.S. Department of State as a major background document for the U.S. national paper, 1979 United Nations Conference on Science and Technology for Development.

31. Proceedings, International Workshop on Energy Survey Methodologies for Developing Countries. 1980. 220 pp. Report of a 1980 workshop organized to examine past and ongoing energy survey efforts in developing countries. Includes reports from rural, urban, industry, and transportation working groups, excerpts from 12 background papers, and a directory of energy surveys for developing countries. NTIS Accession No. PB 81-122-830.

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